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A STUDY OF INVENTORY DECISION RULES FOR SELECTING ITEMS FOR STOCKAGE UNDER BUDGET CONSTRAINTS

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A STUDY OF INVENTORY DECISION RULES

FOR SELECTING ITEMS FOR STOCKAGE

UNDER BUDGET CONSTRAINTS

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SUMMARY

Although the field of inventory theory abounds with mathematical solutions to typical inventory problems, research indicates that there are few inventory managers who actually incorporate these solutions into their system. They may be unaware of the merits resulting from the adoption of a proven method of control or are prevented by a lack of skill from implementing it. When the system is further complicated by a budget constraint, and items must begin to compete for the available dollars, the manager is faced with a compounding of problems.

The performance, in terms of annual operating cost of ordering, backorders and holding stock, of a theoretical inventory system is examined when that system operates under a budget constraint. Various heuristic decision rules for selecting items for stockage are developed and tested through a simulation model of the system. The parameters of the system such as time between demands, mean demand size and lead time are treated as stochastic variables. The inventory manager is assumed to be capable of determining reorder quantities and reorder positions only by the use of deterministic formulae and these quantities are imposed on the stochastic system.

Results from the simulation tests indicate that a good heuristic decision rule can produce reasonable operating costs. In addition, any rule that does not stock at least some fraction of the optimal order quantity suffers abnormally high backorder cost and as a consequence would

not be considered suitable.

There were three rules which consistently produced the lowest total annual operating cost. They were:

Rule A. Reduce the individual optimal reorder quantities to a level determined from the Lagrangian approximation to the constraint equation.

Rule B. Reduce the individual optimal reorder quantities by a fraction proportional to the constraint.

Rule C. Reduce the individual optimal reorder quantities to a level determined by a weighted percentage of the holding cost.

CHAPTER I

INTRODUCTION

The inventory manager of the business enterprise of today, regardless of the size of that enterprise, is faced with a formidable task in selecting stockage levels for items routinely demanded by the customers, especially when such factors as the space available for storage, the fadishness of some inventory items and most importantly, the amount of capital which the firm feels can be invested in stock, are considered. Of course, the larger the concern, generally the greater the range of items considered; however, the inventory manager of the larger firms will have a wider variety of aids, large scale computers for example, to assist him in the selection process. Additionally, researchers in inventory theory have developed numerous, complex, mathematical techniques that can be used in selecting stockage levels for the individual items in a multi-item inventory system considering a constraint on the budget. Several of these selection methods will be described in the literature survey.

The U. S. Commerce Department states that 96 percent of all United States companies have fewer than 250 employees. Since the number of employees can be roughly equated to the magnitude of the firm's assets, it is not unreasonable to assume that most companies are what can be considered small firms with limited assets. Continuing this premise, it must be accepted that these admittedly exact techniques are beyond the reach of the bulk of inventory managers since these methods require electronic computers to process the programming routines and personnel trained in their application.

What procedure do the majority of inventory managers follow in solving their inventory problems? Do they use some magic formula in responding to upper management's desire for instantaneous, practical approaches to the difficult problem of item selection under budget constraints. Or do they follow, as observed by O. W. Wight (34): "Intuitive approaches to calculating order points usually involve some across the board rules, such as 'We will always reorder when we get down to 45 days of supply' or 'We will always carry a 60 day supply on hand and on order.'" It is felt that most do not have a scientific basis for the method they employ nor do they know the cost of that method. Most rules of thumb work quite well; but some inventory managers are more ingenious than others and their rules are better suited for item selection than others might be. Even the most inventive manager is restricted in the amount of testing he can undertake and will usually develop the "desired" rule to the exclusion of any other and without the knowledge of the cost of accepting that rule.

Purpose of the Research

The objective of this research will be to study a multi-item inventory system which operates under a budget constraint without the expertise and equipment necessary to impose rigid mathematical solutions to the problem of selecting items for stockage. The system thus has a limited budget for inventory and cannot stock the optimal quantity for each item. Analysis of the cost following a variety of "rules of thumb" as applied to item selection will be made. It is assumed that all inventory managers have the capability of formulating individual reorder quantities and reorder positions based upon the Wilson Lot Size formula. Each item in the inventory is assigned a unit cost, a variable cost of backorders, a fixed ordering cost and an inventory holding or carrying cost. The composite cost results for ordering, holding stock, and backorders of each "rule of thumb" will be compared.

Research Procedure

To accomplish the above objective, a model of the inventory system was developed. The model, a multi-item, backorder case model, provided for flexibility in all system parameters, such as, the mean demand size and the reorder quantity. A computer model based upon this system was prepared utilizing FORTRAN IV and GASP II, a FORTRAN based simulation language. The simulation output furnished measures of the system's performance through cumulative costs for ordering, holding stock and backorders.

Survey of the Literature

Research in inventory control techniques has been active since F. W. Harris developed the economic lot size policy in 1915 and the history of this early work is provided by Whitin (33) and Newberry (24). While these initial endeavors were undoubtedly invaluable to the practitioners of the time, they became the building blocks of more recent investigators. The past two decades have seen a flood of follow-on work in the field, all of it seemingly more and more complex, but still generally tied to the single item, economic lot size formulas of the first developers.

In a 1957 publication, Churchman, Ackoff, and Arnoff (8) presented a modified economic lot size model that was capable of determining the order size and total operating cost of a multi-item inventory system. This model, based upon the Wilson lot size equation, could also incorporate storage space and budget constraints and required the solution of equations containing Lagrangian multipliers for each constraint. To minimize an objective function, such as the inventory total cost equation, utilizing Lagrangian multipliers, it is necessary to construct an auxiliary function such that the multiplier, λ, times the constraining function is defined as zero. Taking the partial derivative of the total cost equation, with respect to both the order quantity and the multiplier, an expression relating order quantity and the Lagrangian is obtained. The constrained optimal order size is then found by adjusting the value of λ until the constraint function is satisfied. The final value of λ is generally referred to as the imputed cost of the constraining variable, such as storage space or rental cost. If several constraints, e.g. space and inventory budget costs were active, then an auxiliary function would have to be added to the total cost equation for each constraint. This method of solving for constrained optimal order size quickly becomes insolvable when the number of items in the inventory becomes large.

Holt (18), in attempting to answer the question of how to allocate an available amount of money for an aggregate inventory, eliminated the requirement for use of the Lagrangian multipliers by formulation of decision rules which were functions of the total sales rate, S, and the individual item sales rate, S_i. The model itself is an offshoot of the Wilson Lot Size formula, modified to include such elements as the marginal cost of a common unit of inventory and a factor to account for the relative sales importance of the individual products. The resulting equations provide a method of (i) allocating product inventory given that a decision on total aggregate inventory had already been reached and (ii) establishing the total aggregate inventory in terms of the aggregate sales rate. An approximate solution provides for elimination of the dependence of the system on actual aggregate and individual item sales and substitutes average forecasted quantities for these parameters. Although this model did eliminate the Lagrangian from the calculations it is still necessary to compute an optimal order size for each item in the inventory line.

Davis (9) viewed the multi-item inventory somewhat differently than Holt, although his model also required placing a factor of essentiality on each item in the line. The model realistically took into account such practical system parameters as randomly distributed lead times, backorders and the obsolescence rate. A decision rule is obtained which is a function of (i) the number of demands, (ii) the order, interest, obsolescence and holding costs, and (iii) the essentiality of the item. An iterative procedure is used to find the optimal order size solution for this nonlinear programming problem, in which each inventory item must be examined individually and separate calculations made.

Dzielinski and Gomory (10) observed that linear programming formulations of large scale, multi-item, inventory systems, as proposed by Manne (20), created overwhelming computational problems. The authors proposed a solution to these problems that uses the Dantzig and Wolfe decomposition principle to effectively reduce the number of constraints in the problem. This method applies to linear programs in which the constraints can be partitioned into (p + 1) subsets where p of these subsets are mutually independent. The solution to the inventory problem then requires replacing the original problem with (p + 1) smaller linear programming problems. The model uses the standard economic lot size formulas for determination of optimal production runs. Regrettably, even with a medium size system, inventory problems must be solved on large-scale digital computers when this algorithm is used.

At approximately the same time, Veinott (31) presented another multi-item inventory model which relates the initial inventory on hand during a period i to the quantity on hand immediately after the inventory manager has ordered and received stock. The model is conventional in that it includes the standard cost factors of ordering, holding and shortage, but unique in a way that ordering cost is not fixed for all items. Further, the basis for the model is in the inventory process itself and does not depend on a set of formal equations. Conceding the difficulty in handling a very large inventory system, a factoring or partitioning operation similar to Dzielinski and Gomory is outlined which reduces the problem to the solution of only two subprograms; a step which must be repeated n(n - 1)/2 times. It is obvious that when n is large, even this reduction method is not very helpful.

Evans (12) in 1967 write in part, "that much is known about the control of a single inventory of a single item, but little about multi-product, multi-echelon systems." His attempt at clarification resulted in the development of a dynamic programming model to minimize total costs considering a lost sales case, although it could also be adapted to solutions when backorders were allowed. The normal array of systems parameters were included in the model such as a random distribution of demands and production (ordering) costs. Interestingly, the cost of a lost sale and the inventory carrying cost were dependent upon the number of lost sales during the period and the total number of items of a particular product on hand at the end of a given time period. The basic premise of the model was that all functions were considered to be strictly convex and therefore had a unique point for which cost was at a nimimum. The author admitted that increasing the number of products from the proven two item case causes a rapid increase in the complexity of the optimal policy although the system still retains a single critical point for each item.

By 1969, Herron and Hawley (16) had returned full cycle to the formulation of aggregate inventory policies using the Lagrangian multipliers of Churchman, et al., expanded upon quite extensively by Hadley and Whitin (14). The model was developed to obtain both the initial stockage quantity for a warehouse and then after operations had been underway for some period of time to obtain the optimal reorder quantity. The (Q,r) policy, in which a reorder quantity Q is purchased (or manufactured) when the inventory position reaches a reorder point r, is used exclusively. The operating environment is considered to be stochastic with demands during the replenishment lead time being normally distributed. The normal assumptions of fixed ordering costs and constant inventory carrying costs are made, while two separate methods of handling backorders are considered. In the first method, the backorder is given a dollar stockout penalty while in the second case a service level is applied. The service level is considered appropriate whenever the cost of a stockout cannot be determined and is defined at the ratio of the expected number of stockouts of an item per year to the total annual demand of the item. Since this model is tied to the Lagrangian multiplier technique it suffers the same fatal flaw of the Churchman, Ackoff, and Arnoff model in that large multi-item systems are totally unworkable.

The literature did not reveal any attempt by researchers to devise non-optimum, but implementable systems of selecting stockage items in a multi-item environment.

CHAPTER II

SYSTEM DESCRIPTION

This chapter provides the development of the system model and contains the rationale for selecting the parameters used in the simulation model. A detailed description of the simulation model is presented in Chapter III and Appendix A.

System Model

The research centered on a hypothetical retail business which provides a wide range of consumer products. The inventory system employed by the concern is the continuous review, (Q,r) policy (14). It is assumed that the inventory manager has little or no knowledge of stochastic inventory theory and must resort to deterministic approximations. The reorder quantity is found for each individual item using the deterministic lot size formulas represented by

$$Q_i^* = \left[\frac{2\lambda A}{IC}\right]^{1/2} \left[\frac{\hat{\pi} + IC}{\hat{\pi}}\right]^{1/2}$$

where λ is the mean number of items demanded per year, A is the fixed cost of ordering, I is the inventory carrying cost, C is the unit cost, and $\hat{\pi}$ is the time variable backorder cost. The term $\left[\frac{2\lambda A}{IC}\right]^{1/2}$ is normally referred to as the Wilson Lot Size Formula. There is no fixed cost of a backorder allowed in the model.

The reorder position is given by

$$r^* = \mu - s^*$$

where μ is the lead time demand and s* is the expected number of backorders. s* is found through the formula

$$s^* = \left[\frac{2\lambda AIC}{\hat{\pi}(\hat{\pi} + IC)}\right]^{1/2}$$

and all other terms are as previously defined.

Although the formulas used by the inventory manager are deterministic, the lead time, order size, and time between demands for each item are assumed for most of the research to follow stochastic distributions. Changing the computation of the reorder quantity and reorder position to adhere to a probabilistic model would necessitate the use of mathematics considered beyond the ability of most inventory managers. Analysis conducted in conjunction with this research indicates that the only change that results from switching from a deterministic to a probabilistic model is an increase in the reorder position, which would, of course, reduce the likelihood of a backorder and consequently lower backorder costs.

Since the reorder quantity is found for each item without regard to its impact on the system when items must compete for available dollars, the cost of operating the inventory system is merely the summation of the individual annual variable cost.

As is experienced quite frequently in practice, it is assumed that upper management of this firm has made the decision that the amount of operating funds that can be routinely invested in stock is less than that which would allow the manager to stock all items at their optimum level as determined by the above method. The manager then must choose some method of selecting those items for stockage which does not violate his budget constraint and do so without resorting to involved mathematical solutions.

Setting of System Parameters

The system parameters were selected partly from previous research data and partly from heuristic logic. There was no attempt to exactly model any specific inventory system. The setting of each of the primary parameters is discussed below.

Unit Cost

The range of the individual item costs closely follows the data used by Miley (22) in his simulation study of parts inventories at the Lockheed-Georgia plant in Marietta, Georgia, with the exception that a lower limit of $2.00 was placed on the stock cost. No intentional effort was made to correlate unit cost and annual demands and in fact, a conscious effort was made to assure independence of the primary parameters: unit cost, inventory holding cost, backorder cost, and annual demand rate.

Inventory Holding Cost

A survey of both past and current literature reveals a wide dispersion of thought on realistic values for inventory holding cost. While Hadley and Whitin (14) in Chapter 9 state that the opportunity cost is the most important component of inventory holding cost, there is considerable disagreement with this premise. In research conducted in Atlanta, Georgia, Byrne and Lynch (6) found that the opportunity cost of six percent was but 13.6 percent of the total inventory carrying cost in an actual situation. The inventory holding cost of 44 percent in that particular firm was the highest figure found quoted in the literature. Most authors considered a flat, fixed charge for all items in the inventory; in fact, the U. S. Department of Commerce, in 1961, recommended a fixed rate of 0.25 for all items. It seems unreasonable, however, to assume that each item in an inventory system incurs the same fixed charge for stockage over a period of time. If all other components of the inventory carrying cost remain constant, small, highly pilferable, high dollar items may require a higher degree of security and with this a higher carrying cost than a similar dollar value of large bulky items. Diamond rings and automobiles are a good example of this contrast. Consequently, a variable inventory holding cost was assigned to each item analyzed in the simulation. A minimum value of 0.15 dollars per dollar of stock held per year was selected as this corresponded to the minimum in the literature (19). A maximum limit of 0.35 was used and all intermediate values found through use of a table of uniform random numbers.

Backorder Cost

Researchers are divided on the optimal policy of assigning backorder costs as was the case for inventory holding cost, but backorder cost is a unique variable in itself since it may contain both a fixed, time independent cost, and a variable or time dependent cost. Herron (17) suggests five approaches to the setting of backorder cost, all fixed, while Evans (12) recommends that the cost of a stockout depends only upon the number of items out of stock at the end of a period. Countering these, Hadley and Whitin (14) show that the optimal policy does not tend to be very sensitive to backorder costs and any figure, as long as it is of the right magnitude, is adequate.

It was felt that a time variable cost was more reasonable for backorders while a fixed rate would be of interest for the case of lost sales. A variable backorder cost, drawn from a uniform distribution, was assigned to each item in the simulation on a random basis and it can be noted that some low dollar items have a rather large backorder cost. Analogies of this situation are readily available.

Ordering Cost

Most authors were in agreement that the cost of preparing and receipting an order is essentially the same for all items in the inventory system. Examples can be seen in Fetter and Dalleck (13), Jacobs (19) and Miley (22). The value selected for the simulation was chosen arbitrarily from the range found in the literature.

Lead Time

The lead time was established as a function of the item cost according to the following criteria

Unit Cost (C_i)	Lead Time (Days)
$C_i \leq 10$	7
$10 < C_i \leq 30$	14
$30 < C_i \leq 50$	21
$C_i > 50$	30

Lead times were assumed to be normally distributed after Bonini (1), while the range of lead times follows Miley (22). The upper and lower values of the lead time were centered on the mean with the probability of exceeding those values given as 0.001. As will be discussed later, analysis of the effectiveness of the decision rules required changing the lead times to determine the effect of varying lead times on operating cost.

Mean Demand Size

Unlike the majority of mathematical models that have been developed, the research inventory system does not limit the demand size to unity. By allowing for non-unity of demand size, the accepted assumptions of Poisson distribution for the demand size cannot be made even in those situations where the lead time demand is less than 25. (See System Model description for additional discussion of this interaction between lead time demand, mean demand size and the reorder quantity.) Consequently, all items were initially assumed to have a normal distribution of demands. The minimum value of an individual demand was selected as one, while the upper limit was chosen to be the mean plus 25 percent of the mean and the probability of exceeding the maximum was chosen as 0.001. The mean number of demands per year parallels the data presented by Miley (22). It should again be noted that there was no attempt made to correlate unit cost and mean number of demands per year.

Time Between Demands

There was nothing to prevent the occurrence of more than one demand per day, but the combination of mean demands per year and the mean number of orders received per year did not produce this situation. Although the time between demands is usually assumed to be exponentially distributed, the model was developed with a normal distribution for uniformity with the other probabilistic parameters. While attempting to determine the consistency of each rule, the assumption of normality of time between demands was relaxed and the system simulated under both a uniform time between demands and a fixed, or deterministic time.

Decision Rules

There are an unlimited number of decision rules that could be developed for the selection of items for stockage in a constrained budget, multi-item inventory system. Some rules have an intuitive appeal; some, such as selection of those items having low backorder costs, are at first glance discarded. Yet, until a total cost analysis is completed, it is not possible to state categorically that one rule is superior to another. The "rules of thumb" used in the simulation are discussed below.

Lagrangian Reorder Quantity-Rule Number 1

This rule used the Lagrangian solution to the constraint equation to find the constrained reorder quantities. A further discussion of the procedure for determining the actual value of the multiplier is presented later in this chapter.

Maximum Ratio of Ordering Cost to Total Carrying Cost-Rule Number 2

This rule, like many of the others that are basically only ordering rules, follow a similar pattern in the selection of items for stockage. All items are first ranked, in this case, by decreasing magnitude of the ratio of ordering cost to total inventory carrying cost (A/IC). The reorder quantity of each item is multiplied by its unit cost and these individual costs are summed until the budget limit is reached. All items which fall outside the limit are not stocked while those inside are stocked with reorder quantities and positions as determined from the methods previously outlined. All items in the inventory that are not stocked are backordered whenever a demand is made on the system. Rules 2 through 9 are of the stock-no stock variety.

Maximum Ratio of Ordering Cost to Carrying Cost-Rule Number 3

This rule, similar to the one immediately above, ranks all items by decreasing magnitude of the ratio of ordering cost to inventory carrying cost disregarding the cost of the item itself, (A/I). Inventory managers who were concerned about the inherent cost and frequency of ordering stock would be more inclined to order those items whose ordering cost was lowest. With a fixed cost of ordering, the manager would be concerned with the holding cost for each item as well as the ordering cost.

Selection of Those Items Which Are Fast Moving-Rule Number 4

The inventory manager, concerned as he is, with supporting customer needs, would intuitively be inclined to stocking those items which are demanded most frequently. This rule ranks the inventory in decreasing annual demand size, and items are selected until the budget limit is reached.

Selection of Those Items Which Are the Lowest in Cost-Rule Number 5

This is less apparent as a practical approach to item selection than the selection of fast moving items, in that some expensive items may also be among the faster moving items in the inventory. At first glance it might appear that this rule would provide for a greater number of product lines to be selected since the individual item cost is lower, but the reorder quantities of these lower value items provided for only the average number of lines to be selected. ("The average number of lines selected" refers to those rules where items which fall outside the budget limit are not stocked at all, as opposed to other rules which allow for stockage of some percentage of the optimal reorder quantity.)

Select Those Items Which Have the Maximum Lead Time-Rule Number 6

This rule offers a seemingly pragmatic approach in that those items which require the longest time for receipt are the principal items stocked. The items are first ranked by decreasing load time and then by increasing cost within each lead time group. Selection is made until the sum of the reorder quantities multiplied by the unit cost reaches the budget constraint.

Select Those Items With the Highest Backorder Cost-Rule Number 7

Arranging the inventory items by decreasing cost of backorders, provides another practical insight into item selection. Since each item in this inventory system has a different backorder cost it is possible to provide for complete differentiation within items. The number of lines stocked is once again eight, the average for the eight stock-no stock rules.

Select Those Items Which Have the Maximum Cost-Rule Number 8

This rule is the antithesis of the previously discussed low value or minimum cost rule.

Select Those Items With the Lowest Backorder Cost-Rule Number 9

The last of the stock-no stock rules is the contrary of the highest backorder cost described above.

Reduce All Reorder Quantities by One-Half-Rule Number 10

All subsequent rules, including this one, stock some fraction of the optimal reorder quantity as determined by the method described at the beginning of this chapter Since the budget constraint imposed upon the inventory system was one-half of the normal operating budget, one possible method of reaching that limit is to reduce the reorder quantity by the same factor.

Reduce All Reorder Quantities to a Weighted Percentage of Unit Cost-Rule Number 11

Two variations of stockage using the unit cost as the criteria were developed under the stock-no stock concept. This rule attempts to overcome the difficulties presented when some items in the system are never stocked and always backordered. A ratio, called R_i, of the square root of the inverse of each item cost to the square root of the inverse of the minimum unit cost was found. Using these weighting factors with the reorder quantities and unit costs a constraint equation was prepared in terms of the multiplier Z. After solving for Z, reduced reorder quantities, Q_i were found. The following generalized procedures apply to all subsequent rules which rely upon a weighted percentage as the basis.

$$R_i = \frac{\left[\frac{1}{C_i}\right]^{1/2}}{\left[\frac{1}{C_{Min}}\right]^{1/2}} \quad ; \quad i = 1,2,\ldots,17$$

$$Z = \left[R_i \frac{Q_i^*}{2} C_i + R_{i+1} \frac{Q_{i+1}^*}{2} C_{i+1} + \ldots \right] = \text{Budget Limit}$$

$$Q_{C_i} = R_i \cdot Q_i^* \cdot Z$$

Reduce All Reorder Quantities to a Weight Percentage of K_i-Rule Number 12

Hadley and Whitin (14) develop in Chapter 2 a cost, K_i, which is a measure of the cost of ordering and holding stock where

$$K_i = \left[2\lambda A \ I_i \ C_i\right]^{1/2}$$

This cost factor, in a multi-item inventory, assigns a degree of importance to the annual demand rate and item cost, so that the faster moving items, since the demand rate usually overpowers the unit cost, are given a high ranking. The ratio R_i for this rule is

$$R_i = \frac{\left[2\lambda_i \ A \ I_i \ C_i\right]^{1/2}}{\left[2\lambda_i \ A \ I_i \ C_{i \ Max}\right]^{1/2}}$$

Z and Q_{C_i} are found as above.

Reduce All Reorder Quantities to a Weighted Percentage of Annual Demands-Rule Number 13

The annual demand rate was used as the selection criteria for one of the stock-no stock rules. This rule allows for stockage of at least part of the optimal reorder quantity through use of the ratio R_i where R_i is given now by

$$R_i = \frac{\left[\lambda_i\right]^{1/2}}{\left[\lambda_{Max}\right]^{1/2}}$$

while Z and Q_i are found as described above.

Reduce All Reorder Quantities to a Weighted Percentage of Holding Cost-Rule Number 14

The ratio of ordering cost to inventory holding cost was the basis for a stock-no stock rule and since ordering cost was fixed, this ratio ranked the inventory as if all items had been ranked in increasing magnitude of holding cost. The multipliers for this rule were found by

$$R_i = \frac{\left[\frac{1}{I_i}\right]^{1/2}}{\left[\frac{1}{I_{Min}}\right]^{1/2}}$$

and Z and Q_i as above.

Reduce All Reorder Quantities to a Weighted Percentage of the Product of Unit Cost and Annual Demands-Rule Number 15

The last rule follows the general ABC concept in that those items with the greatest annual demand rate, in conjunction with relatively high unit cost, are stocked in greater proportion of the optimal unconstrained reorder quantity. Z and Q_i are found as described above, while

$$R_i = \left[\frac{\lambda_j \quad C_j}{(\lambda_j \quad C_j)_{Max}}\right]$$

It is conceivable that additional rules could be formulated which would have results closer to optimal than those studied in this research.

Quasi-Optimal Reorder Quantities

Although the simulation model was, for the most part, completely stochastic, as regards to lead times, demand size and the time between demands, an attempt was made to compute the constrained budget reorder quantities using the Lagrangian multiplier technique assuming completely deterministic demands. The deterministic multi-item inventory solution is given by Churchman et al. (8) and Hadley and Whitin (14) and will not be derived here. A computer program was prepared to solve the equation of

$$\sum_{j=1}^{17} \left[\frac{2\lambda_j \, C_j \, A}{I_j + 2\theta^*} \right]^{1/2} = \text{Budget Limit}$$

where $j = 1,2,\ldots,17$ and θ^* was found to be approximately 0.370. Reorder quantities were then determined using the multiplier and the formula

$$Q_j^* = \left[\frac{2\lambda_j \, A}{C_j \, (I_j + 2\theta^*)} \right]^{1/2}$$

While the Lagrangian technique does provide for an exact solution, it must be considered for this experiment as only an approximation since the system was not deterministic.

CHAPTER III

SIMULATION EXPERIMENT

The various decision rules were evaluated by means of a computer simulation analysis. A simulation approach was chosen as it has generally proven successful in testing various types of inventory systems. All of the simulation programs in this research were exercised on the UNIVAC 1108 computer at the Georgia Institute of Technology.

The Program

As stated in Chapter I, the computer program to model the research inventory system was written in GASP II, a FORTRAN based simulation language. In this language, the user furnishes FORTRAN subroutines to describe the particular characteristics of his model while the GASP II subroutines provided the time keeping and basic data gathering procedures for the simulation.

The simulation model consisted of the main program and 31 subroutines of which 24 subroutines are an integral part of the standard GASP II simulation package. Changes were made to GASP to orient it to special requirements existing on the UNIVAC 1108 as were necessary. These changes were very minor and consisted principally of replacing the GASP II uniform random number generator with a subroutine specially oriented to the UNIVAC 1108. A macro flow chart of the simulation program is presented in Figure 1. As is evidenced by the names of the events, all routine

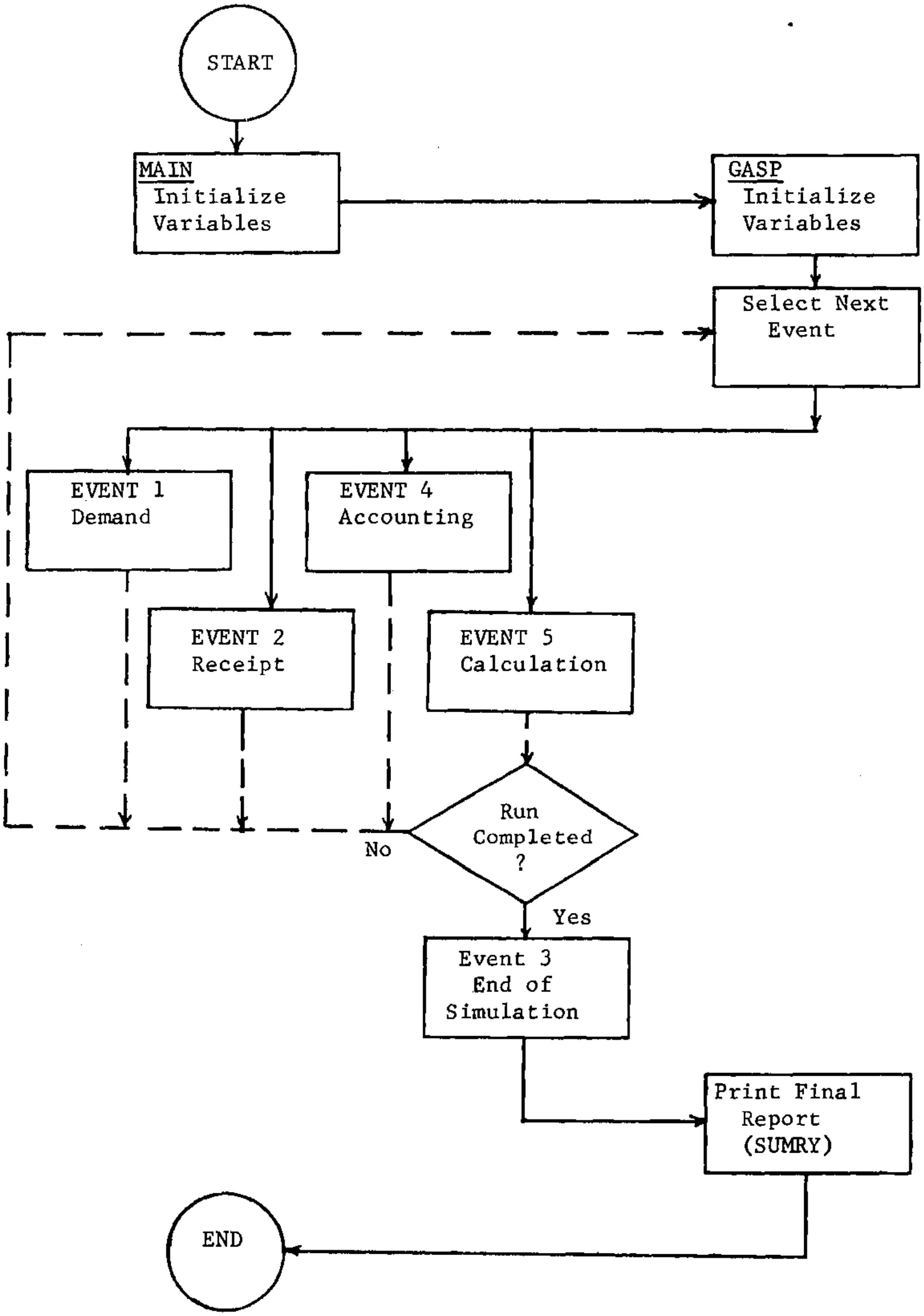

Figure 1. Macro Flow Chart of the Inventory System

transactions normally associated with an inventory system are included in the model used in the research. A listing of the user written subroutines are given in Appendix A, while relevant sections of the program output are shown in Appendix E.

Determination of the Duration of Simulation

When the decision was made to initialize the inventory system at the reorder position, a certain degree of bias entered since the average on hand quantity for those items which are stocked is $\frac{Q_i^*}{2}$ which would not generally equal the reorder position. Output from the model was examined on an annual basis to determine when the effect of the initial conditions was overcome. Simulation runs were made for one to five years and the output for each run was consistent with all other runs. Close examination of individual items revealed that the system had stabilized to normal operating conditions within 50 days of simulation. Consequently, all results are based upon a five year simulation including the initial year of operation.

Statistical Design

There were several considerations which shaped the basic design of the experiment. First and foremost was the need to develop a method of detecting variations within the cost outputs of the simulation runs. The cost of ordering, backorders, and holding stock were selected as the dominant factors which provided the measure of effectiveness of a decision rule. The cost of purchased items was not included as the items would, of necessity, have been procured regardless of the rule followed.

Of other considerations, the average value of inventory held was deemed to be only slightly less important than the ability to detect rule variations. The optimal unconstrained reorder quantities were computed and a simulation run made using those figures to obtain normal, or unconstrained, cost data. The results of this are shown in Table 1. The average on hand stock, in dollars, following the optimal unconstrained policy was $10,776 and efforts were made to reduce this by fifty percent. This was chosen to resemble a constraint that might be encountered in real life inventory systems. As was actually experienced and for the reason to be explained, the actual reduction generally centered around 45 percent.

Table 1. Annual Operating Costs, Unconstrained Inventory

	Original Design($)	Revised Design($)	Change($)
Cost of Ordering	2428.80	2286.40	-142.40
Cost of Backorders	2795.66	2247.19	-548.47
Cost of Holding Stock	2543.28	2749.30	+206.02
Total	7767.74	7282.89	-484.85
Value of Inventory Held	10775.98	11593.90	+817.92
Mean Number of Backorders (Units of Stock)	10.6536	8.9246	- 1.5290

The simulation model was originally developed to adhere strictly to a (Q,r) policy; in other words, when the inventory position dropped to or below the reorder position, the reorder quantity was ordered. The (Q,r) procedure was conceptualized upon the assumption that demands were received one at a time, a requirement which was not carried over to the simulation model. In fact, only five items had a mean demand size equal to one and these five had a maximum demand size of two. For these items the inventory position sometimes became negative and remained negative since the fixed reorder quantity was, on occasion, less than the variable demand size.

The reorder procedure of the simulation model was changed so that the quantity actually ordered consisted of two parts; (i) the reorder quantity as determined using the methods described in Chapter II, and (ii) the difference between the reorder position and the inventory position at the time the order is placed. This change, not unlike a solution the inventory manager would employ, slightly changed the cost of operating the system. Table 1 also describes the changes in operating cost resulting from this revision.

It can be seen that the most dramatic change was in the annual backorder cost which decreased approximately 550 dollars, and correspondingly a decrease of some 14 percent in the mean number of backorders. The reduction was naturally most apparent in those lines which had large mean demand sizes, e.g. Item 2, Mean Demand Size of 60 units.

As a consequence of this revision to the model, the average value of stock held, as computed from the simulation results, for one year increased, decreasing the actual reduction from the unconstrained model costs. As was stated earlier, however, the reduction amounted to approximately 44 percent as compared to a planned 50 percent reduction called for by a budget constraint.

The experiment itself progressed in the following sequence:

(1) Initial simulation runs were conducted using all decision rules with a constant random number generator seed. (The initial seed had been subjected to three tests to insure randomness of the stream. The tests, which were conducted on the first two thousand numbers generated, included (i) Runs Above and Below the Mean Test, (ii) Autocorrelation, and (iii) Chi-Square Frequency Test, all following the format of Schmidt and Taylor (29).)

(2) The random number generator seed was changed and the simulation executed with the most promising decision rules. Five different seeds were used. An F-test was prepared on the cost data for each rule and each random number seed.

(3) The lead time on those items whose lead time exceeded seven days was reduced and those rules tested in (2) above were rerun. An F-test was again made on the cost output to determine if the rules produced operating costs with equal means.

(4) With the lead time fixed as in (3), the distribution was changed for the time between demands from normal to uniform and simulation runs performed on the non-rejected decision rules. As before, an F-test was conducted on the hypothesis that the rules provide costs with equal means.

(5) The assumption of probabilistic distributions was removed from demand size, time between demands and the lead time reducing the simulation model to a deterministic environment. A complete series of runs was then accomplished on the most promising rules and an F-test conducted on the equality of the mean costs.

CHAPTER IV

ANALYSIS OF RESULTS

The results of the experiment are given in Appendix C. Table 17 provides the annual operating cost for the system using the deterministic Lagrangian multiplier approximation to the constraint equation with the random number seed used in the unconstrained solution described earlier. While the average value of inventory held under the Lagrangian approximation decreased by approximately 5100 dollars, the cost of operating the system increased by some 2900 dollars. The mean number of backorders meanwhile increased 61 percent annually.

After the initial run of each decision rule, the rules described in Table 18, Appendix C were discarded from further study in view of their extremely high annual operating costs. It should be noted that these rules were all of the stock-no stock group and each suffered drastically in terms of backorder cost.

Further testing and analysis was then conducted on the following rules:

Rule Number	Description
1	Reduce the reorder quantity to that determined by the Lagrangian approximation solution.
10	Reduce the reorder quantity to one-half the optimal.
11	Reduce the reorder quantity to a weighted percentage of the square root of unit cost.

12	Reduce the reorder quantity to a weighted percentage of the annual cost to order and hold stock.
13	Use a weighting factor found from the annual demands to reduce the reorder quantities.
14	Reduce the reorder quantities to a level determined by a weighted percentage of the holding cost.
15	Use a weighted percentage of the product of the unit cost and annual demands to determine the reorder quantities.

Four additional random number seeds were selected and tested to insure that the random number streams generated using the uniform process generator in the simulation model were in fact random. When it was determined that the generator did produce random number streams, the seed was changed and four additional runs were performed with the decision rules above. The results of these additional passes are presented in Table 19, Appendix C.

Although it was seemingly apparent that there were differences between the mean value of the total operating cost of the rules selected for further testing, an F-test was conducted to determine if there was a discernable difference between the rules. The F-test was selected because of its powerfulness in testing for significant differences between the means of several distributions when it is assumed that the processes, in this situation, the runs, are independent. The first analysis using all of the seven rules selected above provided the results shown in Table 2.

Table 2. ANOVA for Mean Operating Cost

Source	SS	df	MS	F
Between Random Seeds	147,200.00	4	36,800.00	0.64
Within Random Seeds	191,605,376.00	30		
Rules	190,232,128.00	6	31,705,354.50	554.11
Error	1,373,248.00	24	57,218.67	
Total	191,752,576.00	34		

With the size of the Type 1 error, or the probability of rejecting the hypothesis when it is actually correct, set at 0.05, the value of $F_{0.05,6,24}$ is given as 2.51, or considerably less than the value of the test statistic, F = 554.11. In other words there is a significant difference between the mean annual operating cost of each rule. In fact, there is significant difference between all rules except (i) Rules Number 1 and 10 and (ii) Rules 1 and 14 as determined from relationship

$$K = K^* \left[\frac{M.S._2}{r}\right]^{1/2}$$

where the value of K* is found in Table 10.3 in Reference 2.

An additional test was made without including the Lagrangian rule, to determine significance between those strictly heuristic decision rules. The result of this test is presented in Table 3. The analysis indicates that there are discernable and significant differences between the operating costs as determined by simulation with each rule.

Table 3. ANOVA for Mean Operating Cost, Excluding Rule 1

Source	SS	df	MS	F
Between Random Seeds	100,800.00	4	25,200.00	0.37
Within Random Seeds	170,982,464.00	25		
Rules	169,632,128.00	5	33,926,425.50	502.49
Error	1,350,336.00	20	67,516.80	
Total	171,083,264.00	29		

To determine the effect that varying parameters would have on the rules, the lead times for items 8 through 17 were reduced as follows with the accompanying change to Reorder Positions:

Item Number	Revised Lead Time (Days)	Revised Reorder Position
8	5	83
9	5	107
10	5	25
11	5	20
12	5	0
13	5	26
14	3	1
15	3	0
16	3	0
17	3	0

Another series of simulation runs was conducted using the revised lead times and analysis made of the outcome of these runs. Table 4 represents

Table 4. ANOVA for Mean Operating Cost, Revised Lead Time, Phase 1 Distributions

Source	SS	df	MS	F
Between Random Seeds	724,704.00	4	181,176.00	1.02
Within Random Seeds	179,556,320.00	30		
Rules	175,274,976.00	6	29,212,496.00	163.76
Error	4,281,344.00	24	178,389.33	
Total	180,281,024.00	34		

the ANOVA for this series. The value of the test statistic, F = 163.76, indicates that there is a significant difference between the means of the total operating costs of the rules when the lead time is reduced.

Another experiment on the effect on varying parameters, this called Phase 2, was set up where the distribution of the time between demands was changed from a normal to a uniform distribution, with all other distribution remaining as before. Simulation exercises of the seven most favorable rules were conducted and analysis completed on the cost outputs of these runs. The ANOVA is shown in Table 5, while the results are presented in Table 21, Appendix C. Changing one of the parameter distributions did not prevent the differentiation of cost results between the rules as evidenced by the rejection of the hypothesis that the means are equal.

The final revision to the simulation model involved removing the probability distributions from the lead time, time between demands and demand size. The deterministic mode, Phase 3, used the revised lead times

Table 5. ANOVA for Mean Operating Cost, Revised Lead Times, Phase 2

Source	SS	df	MS	F
Between Random Seeds	8,971,392.00	4	2,242,848.00	2.24
Within Random Seeds	388,070,144.00	30		
Rules	364,001,088.00	6	60,666,848.00	60.49
Error	24,069,056.00	24	1,002,877.33	
Total	397,041,536.00	34		

incorporated in the two previous tests and simulation completed on all rules. Table 6 indicates even more vividly than earlier runs, the fact that the mean operating cost of the rules tested are not equal.

Table 6. ANOVA for Mean Operating Cost, Revised Lead Time, Phase 3

Source	SS	df	MS	F
Between Random Seeds	5,792.00	4	1,448.00	2.32
Within Random Seeds	96,843,536.00	30		
Rules	96,828,528.00	6	16,138,088.00	25807.18
Error	15,008.00	24	625.33	
	96,849,328.00	34		

Since Rule 10, or "Reduce the reorder quantity in half," consistently produced the lowest total operating cost but also a generally higher value of inventory held than any other rule, a sensitivity analysis to changing reorder quantities to reduce the average on hand stock value was conducted. Several passes were made varying the reorder quantities but without significant changes in the total cost results.

Intuitively, Rules 1, 10, and 14 appear to produce good results, in that total operating costs are lowest for these regardless of the type distribution or parameter values. No detailed attempt at analyzing the merits of these three rules was made.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

It should be reiterated that this research was concerned with an inventory system that was under the control of a manager that lacked either the skill or the necessary computational capability to apply proven mathematical solutions to multi-item inventory problems.

Conclusions

1. The model provided a suitable framework for testing various decision rules under either deterministic or stochastic environment.

2. A decision rule which does not stock at least some fraction of the optimal reorder quantity will not generally provide a low overall operating cost.

3. Rules 1, 10, and 14 consistently provide the lowest annual operating costs regardless of the stochastic conditions imposed upon the simulation model.

4. Under stochastic demand patterns and lead time, an inventory manager may obtain reasonable results when forced to reduce inventory using a good, heuristic decision rule. Rules 1, 10, and 14 give statistically better results than the other heuristic rules tested.

5. Stochastic inventory analysis differs from deterministic analysis only in the presence of a buffer or safety stock. This buffer stock is necessary to protect against the uncertainty of varying demand patterns.

Under the constrained budget situation, it is necessary to reduce the stock levels down to a point below even the deterministic case, thus eliminating the buffer stock. If the uncertainty of the demand pattern is similar for each item, a good approximation to the optimal solution would be to reduce the deterministic order quantity proportionately with the decrease in the budget. It was not, however, within the scope of this research to investigate the situation where each item in the inventory system had varying demand patterns generated by different distributions. Although the Lagrangian method employed in rule 1 was a deterministic approximation, the rule did provide very good results. This supports the hypothesis that deterministic approximations may yield very good results to some stochastic inventory problems with constraints.

6. While operating costs increased by some 2900 dollars, when a 5100 dollar reduction in average value of stock held was imposed, the converse of this situation is also true. An increase in the budget constrained value of stock held to the optimal deterministic level will cause a reduction of 2900 dollars in annual operating costs.

Recommendations for Further Study

1. A detailed analysis should be made to determine the effect on a constrained inventory budget of varying demand distribution types.

2. A study, involving actual industrial data, to determine the manner in which budget constraints are levied and order policies formulated merits further consideration.

3. Research is needed in analytical approaches to solving multiple constrained stochastic inventory problems under more liberal assumptions.

4. Although the average value of stock held by all rules was effectively the same, the variance around that average is unknown. It is conceivable that, at times, the stock on hand greatly exceeded the desired budget limit. A study of the feasibility of reducing the variance of the dollar investment in inventory is needed. This would involve an investigation of smoothing the order patterns to avoid periods of excessive accounts payable.

APPENDICES

APPENDIX A

SIMULATION MODEL

All simulations were made using the same FORTRAN based program, with the only change made in the data that was read in for each decision rule. All system parameters, except for the reorder quantity and reorder point, remained the same for all runs. The user subroutines are described below.

Main Program

This program provides for initializing the non-GASP portion of the program as well as calling GASP into operation. An illustration of the Main program is provided at Table 7.

Events Subroutine

Once control has been turned over to GASP in the Main program, simulation direction and orientation is provided through the use of tags called event codes. This subroutine provides for the events normally associated with an inventory system; i.e., demands, receipts, inventory or accounting, and calculation of annual operating costs. The ending event for the simulation is also furnished by an event code in this subroutine. Table 8 illustrates the Events subroutine.

Demand Subroutine

The Demand subroutine provides for all contingencies whenever an

Event Code 1, or receipt of a demand, is the event scheduled for processing. Besides determining if sufficient stock is on hand to issue against the demand which was received, the Demand subroutine completes the following actions:

1. Issues stock
2. Orders replenishment stocks
3. Determines the arrival time of the replenishment order
4. Creates backorders if necessary
5. Determines the time of the next demand event
6. Determines the size of the next demand
7. Accumulates statistics on total number of annual demands
8. Accumulates statistics on total number of items ordered
9. Returns control to GASP for selection of the next event.

There are three possible stock conditions that could exist whenever a demand is received. The action taken under each condition is provided below with the description of the stock condition.

1. Stock on hand exceeds demand size. The subroutine issues the entire demand and checks to see if the inventory position has fallen below the reorder position.

2. Stock on hand greater than zero, but less than the quantity demanded. The entire amount on hand is issued and the difference between the quantity demanded and on hand is backordered.

3. Zero stock on hand. The entire demand is backordered. Under some of the "rules of thumb," those which are of the stock-no stock type, where an item is not stocked, the entire demand quantity is automatically backordered.

The Demand subroutine is given in detail in Table 9.

Receipt Subroutine

Replenishment orders which are originated in the Demand subroutine are brought into the system by Event Code 2, the receipt event. The Demand subroutine replenishment procedure was developed so that receipts would always be posted before a demand for an item was received on the same day; therefore, receipts arrive at the beginning of the day. Table 10 depicts the Receipt subroutine.

Receipts can occur under two backorder conditions; (i) backorders on books and (ii) no backorders existing. If there are no current backorders, the stock quantity is incremented and control returned to GASP. However, if there are backorders, two possible courses of action are considered.

1. The new on hand quantity exceeds backorders, whereby, backorders are zeroed out and the issue made for the entire backorder size.

2. The total number of backorders exceeds the quantity just received. Backorders are reduced by the amount received and on hand stocks depleted.

In either event, the subroutine returns control to GASP for continuation of the simulation.

Accounting Subroutine

This subroutine provides the method for the accumulation of information on the average number of items on hand during the period of simulation. Accounting, or more precisely, physical inventory taking, is accomplished on a daily basis throughout the simulation. The details of the subroutine are provided in Table 11.

Calculation Subroutine

This subroutine provides the same type information that would be available to the inventory manager for control purposes. While during the simulation managerial data is provided only on an annual basis and again at the end of the simulation period, the manager would realistically desire information of this nature every month and perhaps bi-weekly. Table 12 illustrates the calculation subroutine.

If the end of simulation is to take place, the initial steps for this event are accomplished within the Calculation subroutine and the end of simulation report, other than the final GASP output, is prepared.

End of Simulation Subroutine

The purpose of this subroutine is to inform GASP (i) that the simulation is completed and (ii) that final GASP summary reports are to be printed. The ENDSM subroutine is described in Table 13.

Table 7. Main Program

```
      DIMENSION NSET(17,100)
       COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
     1 NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,SCALE,ISEED,TNOW,
     2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(30)
       COMMON ATRIB(15),ENQ(30),INN(30),JCELS(20,22),KRANK(30),MAXNQ(30),
     1MFE(30),MLC(30),MLE(30),NCELS(20),NQ(30),PARAM(40,4),QTIME(30),
     2SSUMA(20,5),SUMA(20,5),NAME(6),NPROJ,MON,NDAY,NYR,JCLR
       COMMON DATAI(20,15),IR,IYEAR,ISTOCK,TSTOP,HOLD(17)
C
C ID IS THE NUMBER OF COLUMNS IN NSET
C IM IS THE NUMBER OF ATTRIBUTE ROWS IN NSET
C INIT IS AN INDICATOR
C JEVNT IS THE CODE OF THE EVENT TO BE PROCESSED
C JMNIT IS AN INDICATOR FOR MONITORING
C MFA IS AN IDENTIFIER OF THE FIRST COLUMN IN NSET
C MSTOP IS AN INDICATOR FOR THE METHOD OF STOPPING THE SIMULATION
C MX IS THE SUCCESSOR ROW IN NSET
C MXC IS THE MAXIMUM NUMBER OF CELLS IN ANY HISTOGRAM
C NCLCT IS THE NUMBER OF STATISTIC SETS THAT CAN BE COLLECTED IN COLCT
C NHIST IS THE NUMBER OF HISTOGRAMS THAT CAN BE GENERATED BY HISTO
C NOQ IS THE NUMBER OF FILES IN NSET
C NORPT IS AN INDICATOR FOR SUMMARY AND OUTPUT
C NOT IS THE INDICATOR FOR BEGINNING THE SIMULATION
C NPRMS IS THE NUMBER OF SETS OF PARAMETERS
C NRUN IS THE NUMBER OF THE CURRENT SIMULATION RUN
C NRUNS IS THE NUMBER OF RUNS REMAINING
C NSTAT IS THE NUMBER OF STATISTIC SETS COLLECTED IN TMST
C OUT IS AN INDICATOR FOR DELETING ENTRIES FROM NSET
C SCALE IS A PARAMETER FOR ATTRIBUTES STORED IN NSET
C ISEED IS AN INITIAL RANDOM NUMBER
C TNOW IS THE CURRENT SIMULATION TIME
C TBEG IS THE INITIAL VALUE OF TNOW
C TFIN IS THE TIME TO END THE SIMULATION
C MXX IS THE PREDECESSOR ROW IN NSET
C NPRNT IS THE CODE ASSIGNED TO THE PRINTER (U1108 IS 6)
C NCRDR IS THE CODE ASSIGNED TO THE CARD READER (U1108 IS 5)
C NEP IS AN INDICATOR FOR USE IN DATAN DURING INITIALIZATION
C VNQ(30) IS THE TIME DISTRIBUTION SQUARE OF ENTRIES IN A FILE
C ATRIB IS THE BUFFER FOR ATTRIBUTE VALUES STORED IN NSET
C ENQ IS THE TIME INTEGRATED NUMBER OF ENTRIES IN A FILE
C INN IS THE FILE INDICATOR FOR KRANK
C JCELS IS THE STORAGE ARRAY FOR THE HISTOGRAMS
C KRANK IS THE ATTRIBUTE ROW ON WHICH FILE J IS RANKED
C MAXNQ IS THE MAXIMUM NUMBER OF ENTRIES IN FILE J
C MFE IS THE FIRST ENTRY IN FILE J
C MLC IS THE NEXT ENTRY IN FILE J TO BE REMOVED
C MLE IS THE LAST ENTRY IN FILE J
C NCELS IS THE NUMBER OF CELLS IN HISTOGRAM J
C NQ IS THE CURRENT NUMBER OF ENTRIES IN FILE J
C PARAM IS THE ARRAY FOR STORING PARAMETER VALUES
C QTIME IS THE TIME OF THE LAST USE OF FILE J
C SSUMA IS THE ARRAY FOR STORING TIME STATISTICS GENERATED BY TMST
C SUMA IS THE ARRAY FOR STORING STATISTICS GENERATED BY TMST
C NAME IS THE PROGRAMMERS NAME
C NPROJ IS THE PROJECT NUMBER
C MON IS THE MONTH NUMBER
C NDAY IS THE DAY NUMBER
C NYR IS THE YEAR NUMBER
C JCLR IS THE INDICATOR USED FOR REPEATING THE SIMULATION WITHOUT
C   CLEARING STORAGE AREAS
C
C
C THIS IS THE MAIN PROGRAM FOR AN INVENTORY SIMULATION USING GASP.
C   THE SIMULATION IS DESIGNED TO STUDY VARIOUS DECISION RULES IN
C   SELECTING ITEMS FOR STOCKAGE UNDER A BUDGET CONSTRAINED ENVIRONMENT
C
C SET CARD READER AND PRINTER NUMBERS FOR USE ON THE U1108
C
      NCRDR=5
      NPRNT=6
C
C THE VARIABLE K IS USED IN THE RANDOM NUMBER GENERATOR FOUND IN SUB-
C   ROUTINE NUMBER 14
C
      K=0
C
C THE VALUES USED FOR THE STARTING INVENTORY POSITION ARE OBTAINED FROM
C   EACH DECISION RULE. THIS VALUE DESIGNATED AS REORDI IS READ INTO
C   DATAI AND ATRIB DURING THE INITIALIZING PROCEDURE. THE REORDER QUA-
C   NTITY OR QSTOCI IS ALSO READ IN DURING THIS ROUTINE.
C
   10 FORMAT(I5,F10.0)
   15 FORMAT(F5.0,3F6.0,F7.0,4F6.0,F8.2,F8.3,F8.2,/,F6.2,F4.1,F12.0)
C
C THE ARRAY DATAI(I,J) IS USED TO MAINTAIN INFORMATION ON EACH ITEM IN
C   THE SIMULATION. IT IS A MORE CONVENIENT ARRAY FOR DATA KEEPING THAN
C   NSET.
C
      DO 20 I=1,20
      DO 25 J=1,15
   25 DATAI(I,J)=0
   20 CONTINUE
      READ(NCRDR,10)ISTOCK,TSTOP
      ISTOP=TSTOP+0.00001
      WRITE(NPRNT,55)
      WRITE(NPRNT,110)ISTOCK,ISTOP
  110 FORMAT(T10,'THE VALUE OF ISTOCK IS  ',I5,5(/),T10,'THE VALUE OF IS
     1TOP IS  ',I10,5(/))
      WRITE(NPRNT,55)
```

Table 7. (Continued)

```
      WRITE(NPRNT,115)                                                  MAIN083+
  115 FORMAT(T45,'INITIAL CONDITION OF DATAI(I,J)',2(/))                MAIN083+
      WRITE(NPRNT,120)                                                  MAIN0835
  120 FORMAT(T2,'COLUMN NO.',T13,'1',T18,'2',T24,'3',T30,'4',T37,'5',T43MAIN0836
     1,'6',T49,'7',T55,'8',T61,'9',T68,'10',T75,'11',T84,'12',T90,'13',TMAIN0837
     296,'14',T107,'15',2(/))                                           MAIN0838
      DO 30 I=1,ISTOCK                                                  MAIN084
    3 READ(NCRDR,15)(DATAI(I,J),J=1,15)                                 MAIN085
      DO 21 I=1,ISTOCK                                                  MAIN086
   50 FORMAT(T10,F5.0,3F6.0,F7.0,4F6.0,F8.2,F8.3,F8.2,F6.2,F4.1,F12.0)  MAIN087
   21 WRITE(NPRNT,50)(DATAI(I,J),J=1,15)                                MAIN088
      WRITE(NPRNT,130)                                                  MAIN0881
  130 FORMAT(T10,'COLUMN 1   PRODUCT NUMBER',/,T10,'COLUMN 2   ON HAND QMAIN0882
     1UANTITY',/,T10,'COLUMN 3   DUE IN QUANTITY',/,T10,'COLUMN 4   CURRMAIN0883
     2ENT NUMBER OF BACKORDERS',/,T10,'COLUMN 5   INVENTORY POSITION',/,MAIN0884
     3T10,'COLUMN 6   CUMULATIVE BACKORDERS',/,T10,'COLUMN 7   NUMBER OFMAIN0885
     4 ORDERS PLACED TO DATE',/,T10,'COLUMN 8   QUANTITY ORDERED',/,T10,MAIN0886
     5'COLUMN 9   REORDER QUANTITY',/,T10,'COLUMN 10  UNIT COST',/,T10,'MAIN0887
     6COLUMN 11  INVENTORY HOLDING COST',/,T10,'COLUMN 12  BACKORDER COSMAIN0888
     7T',/,T10,'COLUMN 13  ORDERING COST',/,T10,'COLUMN 14  MEAN TIME BEMAIN0889
     8TWEEN DEMANDS',/,T10,'COLUMN 15  NUMBER ORDERED IF QSTOCI IS ZERO'MAIN088+
     9)                                                                 MAIN088+
      WRITE(NPRNT,55)                                                   MAIN089
   55 FORMAT(1H1)                                                       MAIN090
C
C THE VARIABLE IR CORRESPONDS TO THE DECISION RULES USED IN THE SIMULAT- MAIN091
C
C   ION AND IS USED IN SUBROUTINE 30.                                   MAIN092
      READ(NCRDR,100)IR                                                 MAIN093
  100 FORMAT(I5)                                                        MAIN094
C
C SET THE INITIAL VALUE OF IYEAR FOR CALC SUBROUTINE                    MAIN095
C
      READ(NCRDR,100)IYEAR                                              MAIN096
C
C INITIALIZE HOLD(I) FOR USE IN THE CALC SUBROUTINE.                    MAIN098
C
      DO 300 I=1,ISTOCK                                                 MAIN099
  300 HOLD(I)=0.0                                                       MAIN100
      CALL GASP(NSET)                                                   MAIN101
      END
```

Table 8. Events Subroutine

```
      SUBROUTINE EVNTS(I,NSET)
      DIMENSION NSET(17,1)
      COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
     1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,SCALE,ISEED,TNOW,
     2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(30)
      COMMON ATRIB(15),ENQ(30),INN(30),JCELS(20,22),KRANK(30),MAXNQ(30),
     1MFE(30),MLC(30),MLE(30),NCELS(20),NQ(30),PARAM(40,4),QTIME(30),
     2SSUMA(20,5),SUMA(20,5),NAME(6),NPROJ,MON,NDAY,NYR,JCLR
      COMMON DATAI(20,15),IR,IYEAR,ISTOCK,TSTOP,HOLD(17)
      GO TO (1,2,3,4,5),I
    1 CALL DMAND(NSET)
      RETURN
    2 CALL RECPT(NSET)
      RETURN
    3 CALL ENDSM(NSET)
      RETURN
    4 CALL ACCT(NSET)
      RETURN
    5 CALL CALC(NSET)
      RETURN
      END
```

Table 9. Demand Subroutine

```
      SUBROUTINE DMAND(NSET)
      DIMENSION NSET(17,1)
      COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
     1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,SCALE,ISEED,TNOW,
     2TBEG,TFIN,MXX,NPRNT,NCROR,NEP,VNQ(30)
      COMMON ATRIB(15),ENQ(30),INN(30),JCELS(20,22),KRANK(30),MAXNQ(30),
     1MFE(30),MLC(30),MLE(30),NCELS(20),NQ(30),PARAM(40,4),QTIME(30),
     2SSUMA(20,5),SUMA(20,5),NAME(6),NPROJ,MON,NDAY,NYR,JCLR
      COMMON DATAI(20,15),IR,IYEAR,ISTOCK,TSTOP,HOLD(17)
      I=ATRIB(3)+0.00001
      ONHAN=DATAI(I,2)
      DUEIN=DATAI(I,3)
      BAC=DATAI(I,4)
      INPOS=DATAI(I,5)
      CUMBAC=DATAI(I,6)
      ORD=DATAI(I,15)
    1 OSTOCI=DATAI(I,9)
    2 REORDI=ATRIB(10)
    3 DEM=ATRIB(11)
C
C TEST TO SEE IF THE ITEM DEMANDED IS ONE OF THOSE THAT IS STOCKED ACCORD-
C   ING TO THE RULE USED. IF NOT,ORDER DEM,AND INCREMENT DUEIN,BAC,CUM-
C   BAC AND INPOS.
C
      IF(DATAI(I,9).LT.1.0)GO TO 100
      ORD=ORD+DEM
C
C TEST THE PRESENT ON HAND STOCK TO DETERMINE IF SUFFICIENT TO SATISFY
C   THE DEMAND.
C
    5 IF(ONHAN.GE.DEM)GO TO 30
C
C IF ON HAND STOCKS ARE NOT ADEQUATE TEST TO SEE IF GREATER THAN ZERO.
C
   10 IF(ONHAN.GT.0)GO TO 40
C
C IF THE ON HAND STOCKS ARE AT ZERO,INCREASE BACKORDERS AND CHECK IN-
C   VENTORY POSITION IN RELATION TO THE REORDER POINT.
C
   11 CALL TMST(BAC,TNOW,I,NSET)
      BAC=BAC+DEM
   12 INPOS=INPOS-DEM
   13 CUMBAC=CUMBAC+DEM
   14 GO TO 60
C
C IF ON HAND STOCKS CAN SATISFY THE PRESENT DEMAND,ISSUE AND CHECK FOR
C   REORDER CONDITION.
C
   30 ONHAN=ONHAN-DEM
   31 INPOS=INPOS-DEM
   6  IF(INPOS.LE.REORDI)GO TO 80
C
C IF THE REORDER POINT HAS NOT BEEN REACHED,SET VALUES FOR DATAI.
C
      GO TO 50
C
C IF ON HAND STOCKS ARE GREATER THAN ZERO BUT LESS THAN DEMANDED,SAT-
C   ISFY WITH WHAT IS ON HAND AND BACKORDER THE REMAINDER. CHECK ALSO
C   ON RELATIONSHIP OF INVENTORY POSITION AND REORDER POINT.
C
   40 CALL TMST(BAC,TNOW,I,NSET)
      BAC=DEM-ONHAN
   41 INPOS=INPOS-BAC-ONHAN
   42 CUMBAC=CUMBAC+BAC
   43 ONHAN=0
   44 GO TO 60
C
C IF THE INVENTORY POSITION HAS FALLEN BELOW THE REORDER POINT,REORDER
C   OSTOCI AND INCREMENT THE DUEIN FILE AND NUMBER OF ORDERS,ORNUM,GEN
C   ERATE THE ARRIVAL TIME OF THE ORDER ORIGINATED.
C
C
C IF THE QUANTITY DEMANDED IS GREATER THAN THE REORDER QUANTITY AND THE
C   INVENTORY POSITION IS LESS THAN THE REORDER POSITION ORDER OSTOCI
C   PLUS THE DIFFERENCE BETWEEN REORDI AND INPOS. THIS PROCEDURE IS USED
C   TO CIRCUMVENT THE NON-UNITY OF DEMANDS.
C
   80 BAL=REORDI-INPOS
      DUEIN=DUEIN+OSTOCI+BAL
      INPOS=INPOS+OSTOCI+BAL
      SEM=OSTOCI+BAL
      ATRIB(9)=SEM
      DATAI(I,8)=DATAI(I,8)+SEM
   82 DATAI(I,7)=DATAI(I,7)+1.0
   83 ATRIB(2)=2+0.00001
      J=ATRIB(8)+0.00001
      IAT=TNOW+RNORM(J)+0.50
      ATRIB(1)=IAT
   85 CALL FILEM(1,NSET)
   86 GO TO 50
C
C IF OSTOCI IS ZERO,BACKORDER THE ENTIRE DEMAND.
C
  100 CALL TMST(BAC,TNOW,I,NSET)
      BAC=BAC+DEM
      INPOS=INPOS-DEM
      CUMBAC=CUMBAC+DEM
      DUEIN=DUEIN+DEM
      INPOS=INPOS+DEM
```

Table 9. (Continued)

```
          ORD=ORD+DEM                                                  DMAN0617
          ATRIB(9)=DEM                                                 DMAN0618
          GO TO 82                                                      DMAN062
C
C  FTER ALL POSSIBLE CONDITIONS HAVE BEEN EXAMINED,THE ARRIVAL TIME OF  DMAN063
C   THE NEXT DEMAND AND ITS SIZE ARE TO BE CALCULATED. CONTROL IS THEN  DMAN064
C   RETURNED TO EVNTS.                                                  DMAN065
C
    50 DATAI(I,2)=ONHAN                                                 DMAN067
    51 DATAI(I,3)=QUEIN                                                 DMAN068
    52 DATAI(I,4)=BAC                                                   DMAN069
    53 DATAI(I,5)=INPOS                                                 DMAN070
    54 DATAI(I,6)=CUMBAC                                                DMAN071
    55 DATAI(I,15)=ORD                                                 DMAN0711
    7  ATRIB(2)=1.0+0.00001                                             DMAN073
          J=21.00001+ATRIB(3)                                           DMAN074
          ATRIB(1)=TNOW+RNORM(J)                                        DMAN075
          J=4.00001+ATRIB(3)                                            DMAN076
          IDS=RNORM(J)+0.5                                              DMAN077
          ATRIB(11)=IDS                                                DMAN0771
          CALL FILEM(1,NSET)                                            DMAN078
          RETURN                                                        DMAN079
          END
```

Table 10. Receipt Subroutine

```
      SUBROUTINE RECPT(NSET)
      DIMENSION NSET(17,1)                                              RECE001
      COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,       RECE002
     1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,SCALE,ISEED,TNOW,        RECE003
     2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(30)                             RECE004
      COMMON ATRIB(15),ENQ(30),INN(30),JCELS(20,22),KRANK(30),MAXNQ(30), RECE005
     1MFE(30),MLC(30),MLE(30),NCELS(20),NQ(30),PARAM(40,4),QTIME(30),   RECE006
     2SSUMA(20,5),SUMA(20,5),NAME(6),NPROJ,MON,NDAY,NYR,JCLR            RECE007
      COMMON DATAI(20,15),IR,IYEAR,ISTOCK,TSTOP,HOLD(17)
      I=ATRIB(3)+0.00001                                                RECE0091
    1 ONHAN=DATAI(I,2)                                                  RECE010
    2 DUEIN=DATAI(I,3)                                                  RECE011
    3 BAC=DATAI(I,4)                                                    RECE012
    5 REC=ATRIB(4)                                                      RECE013
C
C INCREMENT ON HAND QUANTITY AND DECREMENT DUE IN QUANTITY.             RECE0131
C
   10 DUEIN=DUEIN-REC                                                   RECE014
   11 ONHAN=ONHAN+REC                                                   RECE015
C
C TEST FOR BACKORDERS. IF NO BACKORDERS RECORDED,PLACE NEW ON HAND QUAN-RECE0151
C    TITY AND DUE IN QUANTITY IN DATAI. RETURN CONTROL TO EVENTS        RECE0152
C
   12 IF(BAC.GT.0.0)GO TO 20                                            RECE016
   13 DATAI(I,2)=ONHAN                                                  RECE017
   14 DATAI(I,3)=DUEIN                                                  RECE018
      RETURN                                                            RECE019
C
C TEST TO SEE IF ON HAND QUANTITY IS GREATER THAN BACKORDERS.IF NOT THE RECE0191
C    NEW BACKORDER QUANTITY IS FOUND. THE ON HAND QUANTITY IS REDUCED TO RECE0192
C    ZERO AND ALL DATA TRANSFERRED TO DATAI.                            RECE0193
C
   20 IF(ONHAN.GE.BAC)GO TO 30                                          RECE020
   21 CALL TYST(BAC,TNOW,I,NSET)                                        RECE021
      BAC=BAC-ONHAN                                                     RECE0211
   22 ONHAN=0                                                           RECE022
   23 DATAI(I,2)=ONHAN                                                  RECE023
   24 DATAI(I,3)=DUEIN                                                  RECE024
   25 DATAI(I,4)=BAC                                                    RECE025
      RETURN                                                            RECE026
C
C IF THE QUANTITY ON HAND EXCEEDS THE BACKORDER QUANTITY,REDUCE BACKOR- RECE0261
C    DER QUANTITY TO ZERO AND TRANSFER DATA TO DATAI.                   RECE0262
C
   30 ONHAN=ONHAN-BAC                                                   RECE027
      CALL TYST(BAC,TNOW,I,NSET)                                        RECE0271
      BAC=0.0                                                           RECE0272
   31 DATAI(I,2)=ONHAN                                                  RECE028
   32 DATAI(I,3)=DUEIN                                                  RECE029
   33 DATAI(I,4)=BAC                                                    RECE030
      RETURN                                                            RECE031
      END
```

Table 11. Accounting Subroutine

```
00101        SUBROUTINE ACCT(NSET)
00103        DIMENSION NSET(17,1)
00104        COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
00104       1IDO,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,SCALE,ISEED,TNOW,
00104       2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(30)
00105        COMMON ATRIB(15),ENQ(30),INN(30),JCELS(20,22),KRANK(30),MAXNQ(30),
00105       1MFE(30),MLC(30),MLE(30),NCELS(20),NQ(30),PARAM(40,4),QTIME(30),
00105       2SSUMA(20,5),SUMA(20,5),NAME(6),NPROJ,MON,NDAY,NYR,JCLR
00106        COMMON DATAI(20,15),IR,IYEAR,ISTOCK,TSTOP,HOLD(17)
00107        DO 1 I=1,17
00112        XOH=DATAI(I,2)
00113      1 CALL COLCT(XOH,I,NSET)
00115        ATRIB(1)=TNOW+1.0
00116        CALL FILEM(1,NSET)
00117        RETURN
00120        END
```

Table 12. Calculation Subroutine

```
      SUBROUTINE CALC(NSET)
      DIMENSION NSET(17,1)                                              CALC001
      COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,       CALC002
     1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,SCALE,ISEED,TNOW,        CALC003
     2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(30)                             CALC004
      COMMON ATRIB(15),ENQ(30),INN(30),JCELS(20,22),KRANK(30),MAXNQ(30), CALC005
     1MFE(30),MLC(30),MLE(30),NCELS(20),NQ(30),PARAM(40,4),QTIME(30),   CALC006
     2SSUMA(20,5),SUMA(20,5),NAME(6),NPROJ,MON,NDAY,NYR,JCLR            CALC007
      COMMON DATAI(20,15),IR,IYEAR,ISTOCK,TSTOP,HOLD(17)
      DIMENSION COSRAY(20,4)                                            CALC010
      DATA((COSRAY(I,J),I=1,20),J=1,4)/80*0.0/
      COSI=0                                                            CALC011
      COSO=0                                                            CALC012
      COSB=0                                                            CALC013
      COSH=0                                                            CALC014
      IYEAR=IYEAR+1                                                     CALC0141
C
C SET THE VALUE OF THE BACKORDERS FOR TNOW EQUAL TO SOME MULTIPLE OF 365CLAC0142
C
      DO 600 I=1,ISTOCK                                                 CALC0143
      XX=DATAI(I,4)                                                     CALC0144
  600 CALL TMST(XX,TNOW,I,NSET)                                         CALC0145
C
C THIS ROUTINE IS USED TO CALCULATE THE ANNUAL OPERATING COSTS OF THE   CALC015
C   SYSTEM. THE RESULTS WILL BE PRINTED OUT ANNUALLY.                   CALC016
C
      DO 1000 I=1,ISTOCK                                                CALC017
      IF(DATAI(I,9).GT.0)GO TO 400                                      CALC0171
      COSRAY(I,1)=DATAI(I,10)*DATAI(I,15)                               CALC0172
      GO TO 500                                                         CALC0173
  400 COSRAY(I,1)=(DATAI(I,8)-COSRAY(I,1))*DATAI(I,10)                  CALC018
  500 COSI=COSI+COSRAY(I,1)                                             CALC019
      COSRAY(I,2)=(DATAI(I,7)-COSRAY(I,2))*DATAI(I,13)                  CALC020
      COSO=COSO+COSRAY(I,2)                                             CALC021
      COSRAY(I,3)=(SSUMA(I,2)-COSRAY(I,4))*DATAI(I,12)/365.0            CALC022
      COSB=COSB+COSRAY(I,3)                                             CALC023
      COSRAY(I,4)=DATAI(I,10)*DATAI(I,11)*(SUMA(I,1)-HOLD(I))/365.0     CALC024
      HOLD(I)=SUMA(I,1)                                                 CALC0241
 1000 COSH=COSH+COSRAY(I,4)                                             CALC025
      WRITE(NPRNT,111)                                                  CALC026
  111 FORMAT(1H1)                                                       CALC027
C
C THIS SEGMENT OF THE ROUTINE WILL PRINT OUT THE ANNUAL OPERATING COSTS CALC028
C   FOR THE SYSTEM UNDER EACH DECISION RULE.                            CALC029
C
      IYEAR=IYEAR+1.0                                                   CALC0291
      WRITE(NPRNT,190)IYEAR                                             CALC030
  190 FORMAT(T58,'YEAR',T63,I5,5(/))                                    CALC031
      GO TO(1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16),IR                  CALC032
    1 WRITE(NPRNT,200)                                                  CALC033
  200 FORMAT(T20,'THE INVENTORY DECISION RULE USED IN THIS SIMULATION WA CALC034
     1S',5(/))                                                          CALC035
      WRITE(NPRNT,205)                                                  CALC036
  205 FORMAT(T25,'NUMBER 1-SELECT THOSE ITEMS WITH THE GREATEST RATIO OF CALC037
     2 ORDERING COST TO INVENTORY COST(A/IC)',5(/))                     CALC038
      GO TO 50                                                          CALC039
    2 WRITE(NPRNT,200)                                                  CALC040
      WRITE(NPRNT,210)                                                  CALC041
  210 FORMAT(T35,'NUMBER 2-SELECT THOSE ITEMS WITH THE GREATEST RATIO OF CALC042
     2 ORDERING COST TO INVENTORY HOLDING COST(A/IC)',5(/))             CALC043
      GO TO 50                                                          CALC044
    3 WRITE(NPRNT,200)                                                  CALC045
      WRITE(NPRNT,215)                                                  CALC046
  215 FORMAT(T35,'NUMBER 3-SELECT THE MAXIMUM NUMBER OF THE FAST MOVING  CALC047
     4ITEMS',5(/))                                                      CALC048
      GO TO 50                                                          CALC049
    4 WRITE(NPRNT,200)                                                  CALC050
      WRITE(NPRNT,220)                                                  CALC051
  220 FORMAT(T35,'NUMBER 4-SELECT THE MINIMUM NUMBER OF THE HIGH VALUE I CALC052
     5TEMS',5(/))                                                       CALC053
      GO TO 50                                                          CALC054
    5 WRITE(NPRNT,200)                                                  CALC055
      WRITE(NPRNT,225)                                                  CALC056
  225 FORMAT(T35,'NUMBER 5-SELECT THOSE ITEMS WHICH HAVE THE MAXIMUM LEA CALC057
     6D TIME',5(/))                                                     CALC058
      GO TO 50                                                          CALC059
    6 WRITE(NPRNT,200)                                                  CALC060
      WRITE(NPRNT,230)                                                  CALC061
  230 FORMAT(T35,'NUMBER 6-SELECT THOSE ITEMS WHICH HAVE THE MAXIMUM BAC CALC062
     7KORDER COST',5(/))                                                CALC063
      GO TO 50                                                          CALC064
    7 WRITE(NPRNT,200)                                                  CALC065
      WRITE(NPRNT,235)                                                  CALC066
  235 FORMAT(T35,'NUMBER 7-SELECT THE MINIMUM NUMBER OF LOW VALUE ITEMS' CALC067
     8,5(/))                                                            CALC068
      GO TO 50
    8 WRITE(NPRNT,200)                                                  CALC0681
      WRITE(NPRNT,237)                                                  CALC0682
  237 FORMAT(T35,'NUMBER 8-USE THE WILSON LOT SIZE FORMULA TO DETERMINE CALC0683
     9THE OPTIMUM REORDER',2(/),T44,'QUANTITY FOR EACH ITEM DISREGARDINGCALC0684
     1 BUDGET LIMITATIONS',5(/))                                        CALC0685
      GO TO 50                                                          CALC6850
    9 WRITE(NPRNT,200)                                                  CALC6851
      WRITE(NPRNT,2000)                                                 CALC6852
 2000 FORMAT(T35,'NUMBER 9-SELECT THOSE ITEMS WHICH HAVE THE MINIMUM BACCALC6853
     1KORDER COST',5(/))                                                CALC6854
      GO TO 50                                                          CALC6855
   10 WRITE(NPRNT,200)                                                  CALC6856
      WRITE(NPRNT,2010)                                                 CALC6857
 2010 FORMAT(T35,'NUMBER 10-REDUCE THE REORDER QUANTITY BY ONE HALF',5(/CALC6858
```

Table 12. (Continued)

```
      2))                                                               CALCA859
       GO TO 50                                                         CALCAA01
   11 WRITE(NPRNT,200)                                                  CALCAA02
      WRITE(NPRNT,2020)                                                 CALCAA03
 2020 FORMAT(T35,'NUMBER 10-REDUCE THE REORDER QUANTITY TO A FIXED NUMBECALCAA04
     3R OF DAYS OF DEMAND',5(/))                                        CALCAA05
      GO TO 50                                                          CALCAA06
   12 WRITE(NPRNT,200)                                                  CALCAA07
      WRITE(NPRNT,2030)                                                 CALCAA08
 2030 FORMAT(T35,'NUMBER 11-REDUCE THE REORDER QUANTITY TO A WEIGHTED PECALCAA09
     4RCENTAGE BASED UPON UNIT COST',5(/))                              CALCAA10
      GO TO 50                                                          CALCAA11
   13 WRITE(NPRNT,200)                                                  CALCAA12
      WRITE(NPRNT,2040)                                                 CALCAA13
 2040 FORMAT(T35,'NUMBER 12-REDUCE THE REORDER QUANTITY TO A WEIGHTED PECALCAA14
     5RCENTAGE BASED UPON',2(/),T44,'ANNUAL COST OF PROCUREMENT AND HOLDCALCAA15
     6ING INVENTORY',5(/))                                              CALCAA16
      GO TO 50                                                          CALCAA17
   14 WRITE(NPRNT,200)                                                  CALCAA18
      WRITE(NPRNT,2050)                                                 CALCAA19
 2050 FORMAT(T35,'NUMBER 13-REDUCE THE REORDER QUANTITY TO A WEIGHTED PECALCAA20
     1RCENTAGE BASED UPON',2(/),T46,'THE DEMAND SIZE',5(/))             CALCAA21
      GO TO 50                                                          CALCAA22
   15 WRITE(NPRNT,200)                                                  CALCAA23
      WRITE(NPRNT,2060)                                                 CALCAA24
 2060 FORMAT(T35,'NUMBER 14-REDUCE THE REORDER QUANTITY TO A WEIGHTED PECALCAA25
     2RCENTAGE BASED UPON',2(/),T46,'THE INVENTORY HOLDING COST',5(/))  CALCAA26
      GO TO 50                                                          CALCAA27
   16 WRITE(NPRNT,200)                                                  CALCAA28
      WRITE(NPRNT,2070)                                                 CALCAA29
 2070 FORMAT(T35,'NUMBER 15-REDUCE THE REORDER QUANTITY TO THE LEVEL DETCALCAA30
     3ERMINED FROM THE',2(/),T46,'LAGRANGIAN MULTIPLIER SOLUTION TO THE CALCAA31
     4CONSTRAINT EQUATION',5(/))                                        CALCAA32
   50 WRITE(NPRNT,240)                                                   CALC069
  240 FORMAT(T49,'COST OF',T67,'COST OF',T82,'COST OF',T99,'COST OF',/T  CALC070
     113,'PRODUCT NO.',T30,'UNIT COST',T45,'PURCHASED ITEMS',T66,'ORDERI CALC071
     2NG',T80,'BACKORDERS',T96,'HOLDING STOCK',/,T13,10('-'),T30,9('-')  CALC072
     3T45,15('-'),T66,8('-'),T80,10('-'),T96,13('-'),2(/))               CALC073
      WRITE(NPRNT,245)(DATAI(I,1),DATAI(I,10),COSRAY(I,1),COSRAY(I,2),CO CALC074
     1SRAY(I,3),COSRAY(I,4),I=1,ISTOCK)                                  CALC075
  245 FORMAT(T16,F5.0,T31,F8.2,T46,F13.2,T65,F10.2,T79,F12.2,T98,F10,2)  CALC076
      WRITE(NPRNT,250)                                                   CALC078
  250 FORMAT(2(/),T45,14('-'),T66,9('-'),T80,11('-'),T96,12('-'),2(/))   CALC079
      WRITE(NPRNT,255)COSI,COSD,COSB,COSH                                CALC080
  255 FORMAT(T49,F10.2,T65,F10.2,T77,F14.2,T98,F10.2)                    CALC081
C
C SET THE NEXT EVENT TIME                                                CALC082
C
      WRITE(NPRNT,111)                                                  CALC0822
      WRITE(NPRNT,190)IYEAR                                             CALC0823
      WRITE(NPRNT,256)                                                   CALC083
  256 FORMAT(T2,'COLUMN NO.',T13,'1',T18,'2',T24,'3',T30,'4',T39,'5',T47 CALC084
     1,'6',T53,'7',T59,'8',T65,'9',T71,'10',T79,'11',T87,'12',T93,'13',T CALC085
     2101,'14',T107,'15',2(/))                                           CALC086
      DO 260 I=1,ISTOCK                                                  CALC087
  259 FORMAT(T10,F5.0,3F6.0,F9.0,F8.0,3F6.0,F8.2,F8.3,F8.2,F6.2,F4.1,F12 CALC088
     1.0)                                                               CALC0881
  260 WRITE(NPRNT,259)(DATAI(I,J),J=1,15)                                CALC089
      WRITE(NPRNT,265)                                                   CALC090
  265 FORMAT(T10,'COLUMN 1   PRODUCT NUMBER',/,T10,'COLUMN 2   ON HAND Q CALC091
     1UANTITY',/,T10,'COLUMN 3   DUE IN QUANTITY',/,T10,'COLUMN 4   CURR CALC092
     2ENT NUMBER OF BACKORDERS',/,T10,'COLUMN 5   INVENTORY POSITION',/, CALC093
     3T10,'COLUMN 6   CUMULATIVE BACKORDERS',/,T10,'COLUMN 7   NUMBER OF CALC094
     4 ORDERS PLACED TO DATE',/,T10,'COLUMN 8   QUANTITY ORDERED',/,T10, CALC095
     5'COLUMN 9   REORDER QUANTITY',/,T10,'COLUMN 10  UNIT COST',/,T10,' CALC096
     6COLUMN 11  INVENTORY HOLDING COST',/,T10,'COLUMN 12  BACKORDER COS CALC097
     7T',/,T10,'COLUMN 13  ORDERING COST',/,T10,'COLUMN 14  MEAN TIME BE CALC098
     8TWEEN DEMANDS',/,T10,'COLUMN 15  NUMBER OF ITEMS DEMANDED')        CALC099
C
C THE NEXT CARD IS CALC 105
C
      DO 700 I=1,ISTOCK                                                  CALC105
C
C SET THE VALUE OF THE LISTED SEGMENTS FOR THE NEXT SERIES OF CALC       CALC106
C   COMPUTATIONS                                                         CALC107
C
      COSRAY(I,1)=DATAI(I,8)                                             CALC108
      COSRAY(I,2)=DATAI(I,7)                                             CALC109
      COSRAY(I,3)=DATAI(I,6)                                             CALC110
      COSRAY(I,4)=SSUMA(I,2)                                             CALC111
  700 DATAI(I,15)=0.0                                                    CALC112
C
C SET THE NEXT EVENT TIME                                                CALC114
C
      ATRIB(1)=TNOW+365.0                                                CALC115
      CALL FILEM(1,NSET)                                                 CALC116
      ISTOP=TSTOP+0.00001                                                CALC117
      IF(IYEAR.GE.ISTOP)GO TO 300                                        CALC118
      RETURN                                                             CALC119
  300 WRITE(NPRNT,111)                                                   CALC120
      WRITE(NPRNT,800)                                                   CALC121
  800 FORMAT(T36,'TOTAL OPERATING COST FOR THE PERIOD OF SIMULATION',5(/ CALC122
     1))                                                                 CALC123
      COSI=0.0                                                           CALC124
      COSO=0.0                                                           CALC125
      COSB=0.0                                                           CALC126
      COSH=0.0                                                           CALC127
      DO 810 I=1,ISTOCK                                                  CALC128
      IF(DATAI(I,9).GT.0.0)GO TO 850                                     CALC129
      COSRAY(I,1)=DATAI(I,8)*DATAI(I,10)                                 CALC130
```

Table 12. (Continued)

```
      GO TO 855                                                      CALC131
  850 COSRAY(I,1)=DATAI(I,8)*DATAI(I,10)                             CALC132
  855 COST=COSI+COSRAY(I,1)                                          CALC133
      COSRAY(I,2)=DATAI(I,7)*DATAI(I,13)                             CALC134
      COSO=COSO+COSRAY(I,2)                                          CALC135
      COSRAY(I,3)=DATAI(I,12)*SSUMA(I,2)/365.0                       CALC136
      COSB=COSB+COSRAY(I,3)                                          CALC137
      COSRAY(I,4)=DATAI(I,11)*DATAI(I,10)*SUMA(I,1)/365.0            CALC138
  810 COSH=COSH+COSRAY(I,4)                                          CALC139
      WRITE(NPRNT,240)                                               CALC140
      WRITE(NPRNT,910)(DATAI(I,1),DATAI(I,10),COSRAY(I,1),COSRAY(I,2),CO CALC141
     1SRAY(I,3),COSRAY(I,4),I=1,ISTOCK)                              CALC142
  910 FORMAT(T16,F5.0,T31,F8.2,T46,F13.2,T65,F10.2,T77,F14.2,T98,F10.2)  CALC143
      WRITE(NPRNT,250)                                               CALC144
      WRITE(NPRNT,920)COSI,COSO,COSB,COSH                            CALC145
  920 FORMAT(T45,F14.2,T63,F12.2,T77,F14.2,T98,F10.2)                CALC146
      WRITE(NPRNT,111)                                               CALC147
      COSI=0.0                                                       CALC148
      COSO=0.0                                                       CALC149
      COSB=0.0                                                       CALC150
      DO 701 I=1,ISTOCK                                              CALC151
      COSRAY(I,1)=SUMA(I,1)/SUMA(I,3)                                CALC152
      COST=COSI+COSRAY(I,1)                                          CALC153
      COSRAY(I,2)=COSRAY(I,1)*DATAI(I,10)                            CALC154
      COSO=COSO+COSRAY(I,2)                                          CALC155
      COSRAY(I,3)=SSUMA(I,2)/SSUMA(I,1)                              CALC156
  701 COSB=COSB+COSRAY(I,3)                                          CALC157
      WRITE(NPRNT,705)                                              CALC1571
  705 FORMAT(T15,'MEAN NUMBER OF ITEMS ON HAND',T53,'COST OF INVENTORY H CALC158
     1ELD',T85,'MEAN NUMBER OF BACKORDERS',/,T15,28('-'),T53,22('-'),T85 CALC159
     2,25('-'),2(/))                                                 CALC160
      WRITE(NPRNT,710)(COSRAY(I,1),COSRAY(I,2),COSRAY(I,3),I=1,ISTOCK)   CALC161
  710 FORMAT(T24,F10.4,T59,F10.2,T96,F10.4)                          CALC162
      WRITE(NPRNT,720)                                               CALC163
  720 FORMAT(2(/),T24,10('-'),T59,10('-'),T96,10('-'),2(/))          CALC164
      WRITE(NPRNT,730)COSI,COSO,COSB                                 CALC165
  730 FORMAT(T24,F10.4,T59,F10.2,T96,F10.4)                          CALC166
      WRITE(NPRNT,111)                                               CALC167
      CALL ENDSM(NSET)                                               CALC168
      RETURN                                                         CALC169
      END
```

Table 13. End of Simulation Subroutine

```
      SUBROUTINE ENDSM(NSET)
      DIMENSION NSET(17,1)
      COMMON ID,IM,INIT,JEVNT,JMNIT,MFA,MSTOP,MX,MXC,NCLCT,NHIST,
     1NOQ,NORPT,NOT,NPRMS,NRUN,NRUNS,NSTAT,OUT,SCALE,ISEED,TNOW,
     2TBEG,TFIN,MXX,NPRNT,NCRDR,NEP,VNQ(30)
      COMMON ATRIB(15),ENQ(30),INN(30),JCELS(20,22),KRANK(30),MAXNQ(30),
     1MFE(30),MLC(30),MLE(30),NCELS(20),NQ(30),PARAM(40,4),QTIME(30),
     2SSUMA(20,5),SUMA(20,5),NAME(6),NPROJ,MON,NDAY,NYR,JCLR
      COMMON DATAI(20,15),IR,IYEAR,ISTOCK,TSTOP,HOLD(17)
      MSTOP=-1
      NORPT=0
      RETURN
      END
```

APPENDIX B

PARAMETER DATA

The values that were either chosen as system parameters, and defined in Chapter II, or calculated, based upon the defined parameters, are tabulated in this appendix.

Table 14 provides the basic system costs per item studied in the simulation, while Table 15 illustrates the demand data for each item. Table 16 is a listing of the reorder quantity and reorder position for each item as determined for each decision rule. The decision rules discussed in Chapter II are related to the Rule Numbers used in this appendix as outlined below.

Rule Number	Description
1	The deterministic Lagrangian multiplier approximation used to determine the constrained optimal reorder quantity.
2	Order all items based upon the ratio of ordering cost to total carrying costs.
3	Order all items based upon the ratio or ordering cost to carrying cost alone.
4	Rank the inventory items in terms of descending mean demands per year.
5	Order the inventory by increasing cost.
6	Use the lead time to rank the items and select those having the maximum lead time.

7	Rank the inventory items in descending order of backorder cost.
8	Order all inventory items in terms of ascending unit cost.
9	Rank the items in ascending order of backorder cost.
10	Reduce the optimal, unconstrained, reorder quantity by one-half.
11	Use a weighted percentage of unit cost to determine reorder quantity.
12	Reduce the reorder quantity of each item by a percentage weighted by the cost of ordering and holding stock ($K = \sqrt{2\lambda AIC}$).
13	Use a weighting factor found from the annual demands to reduce the reorder quantities.
14	Reduce the reorder quantities to a level determined by a weighted percentage of holding cost.
15	Use a weighted percentage of the product of the unit cost and annual demands to determine the reorder quantities.

Table 14. Item Costs

Item Number	Unit Cost ($)	Holding Cost ($/$stocked/yr)	Backorder Cost ($/Backorder/yr)	Ordering Cost
1	2.00	0.301	120.00	8.00
2	2.49	0.187	390.00	8.00
3	4.90	0.322	210.00	8.00
4	5.99	0.192	480.00	8.00
5	6.90	0.211	240.00	8.00
6	9.00	0.216	330.00	8.00
7	9.98	0.219	90.00	8.00
8	11.00	0.283	150.00	8.00
9	18.99	0.308	300.00	8.00
10	19.12	0.200	360.00	8.00
11	23.59	0.194	450.00	8.00
12	30.80	0.206	540.00	8.00
13	36.49	0.199	270.00	8.00
14	53.16	0.221	510.00	8.00
15	74.99	0.303	420.00	8.00
16	85.79	0.304	180.00	8.00
17	103.49	0.201	60.00	8.00

Figure 15. Demand Data for Each Item

Item Number	Mean Demands Per Year	Mean Demand Size	Mean Time Between Demands (Days)
1	875	6	2.4
2	5870	60	3.7
3	6894	25	1.3
4	420	7	6.1
5	255	2	3.0
6	6601	26	1.5
7	3000	30	3.7
8	6308	33	1.9
9	8000	26	1.2
10	1852	8	1.6
11	1500	20	4.9
12	45	1	8.5
13	2000	12	2.2
14	120	1	3.0
15	62	1	6.2
16	41	1	9.4
17	44	1	8.3

Table 16. Reorder Parameters for Each Decision Rule

Item Number	Rule No.1 Q*	r	Rule No.2 Q*	r	Rule No.3 Q*	r	Rule No.4 Q*	r	Rule No.5 Q*	r	Rule No.6 Q*	r	Rule No.7 Q*	r	Rule No.8 Q*	r
1	82	16	153	16	0	0	0	0	153	16	0	0	0	0	0	0
2	202	112	449	112	449	112	449	112	449	112	0	0	449	112	0	0
3	146	130	264	130	0	0	264	130	264	130	0	0	0	0	0	0
4	35	8	76	8	76	8	0	0	76	8	0	0	76	8	0	0
5	25	5	53	5	53	5	0	0	53	5	0	0	0	0	0	0
6	111	125	234	125	0	0	234	125	234	125	0	0	234	125	0	0
7	71	54	149	54	0	0	149	54	149	54	0	0	0	0	0	0
8	95	238	181	238	0	0	181	238	181	238	181	238	0	0	0	0
9	80	304	0	0	0	0	149	304	0	0	153	304	0	0	0	0
10	41	70	88	70	88	70	0	0	0	0	0	0	88	70	88	70
11	33	57	0	0	72	57	0	0	0	0	0	0	72	57	72	57
12	5	2	0	0	11	2	0	0	0	0	11	2	11	2	11	2
13	31	113	0	0	67	113	0	0	0	0	67	113	0	0	67	113
14	6	10	0	0	0	0	0	0	0	0	13	10	13	10	13	10
15	4	5	0	0	0	0	0	0	0	0	7	5	7	5	7	5
16	3	3	0	0	0	0	0	0	0	0	5	3	0	0	5	3
17	3	2	0	0	6	2	0	0	0	0	6	2	0	0	6	2

Table 16. (Continued)

Item Number	Rule No.9 Q*	r	Rule No.10 Q*	r	Rule No.11 Q*	r	Rule No.12 Q*	r	Rule No.13 Q*	r	Rule No.14 Q*	r	Rule No.15 Q*	r
1	153	16	77	16	190	16	16	16	40	16	66	16	2	16
2	0	0	225	112	499	112	111	112	300	112	247	112	60	112
3	264	130	132	130	209	130	130	130	191	130	110	130	81	130
4	0	0	38	8	54	8	8	8	14	8	41	8	2	8
5	53	5	27	5	35	5	5	5	7	5	27	5	1	5
6	0	0	117	125	137	125	126	125	187	125	120	125	126	125
7	149	54	74	54	82	54	56	54	71	54	75	54	40	54
8	181	238	90	238	95	238	120	238	103	238	80	238	113	238
9	27	304	75	304	60	304	152	304	116	304	64	304	205	304
10	0	0	44	70	35	70	34	70	33	70	47	70	28	70
11	0	0	36	57	26	57	28	57	24	57	39	57	23	57
12	0	0	6	2	4	2	1	2	1	2	6	2	1	2
13	67	113	33	113	19	113	38	113	26	113	35	113	44	113
14	0	0	7	10	3	10	2	10	1	10	7	10	1	10
15	0	0	4	5	1	5	1	5	1	5	3	5	1	5
16	5	3	3	3	1	3	1	3	1	3	2	3	1	3
17	6	2	3	2	1	2	1	2	1	2	3	2	1	2

APPENDIX C

OPERATING COSTS AS DETERMINED THROUGH SIMULATION

Table 17. Annual Operating Cost-Constrained Inventory Lagrangian Approximation Solution

Cost of Ordering	4289.60
Cost of Backorders	4146.14
Cost of Holding Stock	1564.60
Total	10000.34
Value of Inventory Held	6496.33
Mean Number of Backorders	14.4250

Table 18. Annual Operating Costs-Constrained Inventory

	Decision Rule No. 2	Decision Rule No. 3	Decision Rule No. 4
Cost of Ordering	8,132.80	12,726.40	10,257.20
Cost of Backorders	159,435.45	210,314.00	100,155.52
Cost of Holding Stock	1,362.83	901.16	1,567.35
Total	168,931.08	223,941.56	111,980.07

	Decision Rule No. 5	Decision Rule No. 6	Decision Rule No. 7
Cost of Ordering	9,787.50	12,200.00	12,011.20
Cost of Backorders	183,813.64	177,421.90	194,617.49
Cost of Holding Stock	1,163.78	1,429.13	952.72
Total	194,764.92	191,051.03	207,581.41

	Decision Rule No. 8	Decision Rule No. 9
Cost of Ordering	13,316.80	10,857.60
Cost of Backorders	251,339.25	151,382.15
Cost of Holding Stock	947.30	1,345.10
Total	265,603.35	163,584.85

Table 19. Annual Operating Costs-Constrained Budget Normal Distribution of Lead Time, Time Between Demands and Demand Size

Run Number	Cost of Ordering	Cost of Backorders	Cost of Holding Stock	Total
		Rule No. 1		
1	4289.60	4146.14	1564.60	10000.34
2	4284.80	4002.08	1562.79	9849.67
3	4278.40	4150.26	1561.03	9989.69
4	4284.80	4086.92	1579.73	9951.45
5	4321.60	4354.95	1533.95	10210.50
		Rule No. 10		
1	4340.80	3681.92	1635.43	9658.15
2	4345.60	3452.13	1624.19	9491.92
3	4358.40	4157.88	1616.25	10132.53
4	4331.20	3620.63	1653.49	9605.32
5	4336.00	3404.53	1646.06	9386.59
		Rule No. 11		
1	5297.60	4690.52	1505.33	11493.45
2	5260.80	4735.09	1519.40	11515.29
3	5270.40	4662.57	1518.50	11451.47
4	5292.80	4903.41	1515.96	11712.17
5	5291.20	4489.83	1510.77	11291.80
		Rule No. 12		
1	6297.60	4151.38	1627.94	12076.92
2	6331.20	4321.19	1619.36	12271.75
3	6288.00	4197.92	1633.58	12119.50
4	6288.00	4046.65	1671.92	12006.57
5	6321.60	4657.65	1654.64	12633.89
		Rule No. 13		
1	6073.60	5020.30	1557.44	12651.34
2	6100.80	4778.97	1566.77	12446.54
3	6097.60	4472.50	1562.34	12132.44
4	6088.00	4552.59	1566.41	12207.00
5	6147.20	4981.11	1536.26	12664.57

Table 19. (Continued)

Run Number	Cost of Ordering	Cost of Backorders	Cost of Holding Stock	Total
		Rule No. 14		
1	4454.40	3946.14	1543.22	9943.76
2	4475.20	4327.28	1510.31	10312.79
3	4480.00	4276.83	1519.46	10276.29
4	4486.40	4390.26	1513.79	10390.45
5	4499.20	4804.92	1495.91	10800.03
		Rule No. 15		
1	8780.80	6567.34	1668.08	17016.22
2	8779.20	6355.55	1666.54	16801.29
3	8740.80	6651.15	1692.48	17084.43
4	8769.60	6875.69	1663.32	17308.61
5	8784.00	6513.29	1671.88	16969.17

Table 20. Annual Operating Costs-Constrained Budget Normal Distribution of Lead Time, Time Between Demands and Demand Size with Reduced Lead Times

Run Number	Cost of Ordering	Cost of Backorders	Cost of Holding Stock	Total
		Rule No. 1		
1	4280.00	3027.62	1578.13	8885.75
2	4288.00	2618.85	1529.26	8428.11
3	4280.00	3092.43	1526.40	8898.83
4	4288.00	3308.11	1523.25	9119.36
5	4312.00	2854.12	1535.23	8701.35
		Rule No. 10		
1	4360.00	2092.87	1631.11	8083.98
2	4400.00	2174.00	1603.44	8177.44
3	4336.00	2598.87	1593.17	8528.04
4	4304.00	3017.33	1618.47	8939.80
5	4304.00	2204.99	1657.72	8166.71
		Rule No. 11		
1	5304.00	2975.01	1485.35	9764.36
2	5352.00	3525.55	1457.94	10335.49
3	5256.00	3216.01	1493.51	9965.52
4	5280.00	3168.34	1453.40	9901.74
5	5296.00	3472.25	1464.19	10232.44
		Rule No. 12		
1	6360.00	3333.05	1515.20	11208.25
2	6248.00	3221.81	1591.59	11061.40
3	6280.00	3129.64	1561.50	10971.14
4	6320.00	2858.52	1571.03	10749.55
5	6280.00	2863.11	1586.96	10730.07
		Rule No. 13		
1	6096.00	3229.66	1522.82	10848.48
2	6112.00	3364.95	1483.24	10960.19
3	6112.00	3426.88	1523.07	11061.95
4	6008.00	3480.95	1548.61	11037.56
5	6040.00	2716.36	1541.16	10297.52

Table 20. (Continued)

Run Number	Cost of Ordering	Cost of Backorders	Cost of Holding Stock	Total
		Run No. 14		
1	4488.00	2523.59	1491.07	8502.66
2	4456.00	2971.45	1516.07	8943.52
3	4416.00	2248.98	1532.00	8196.98
4	4392.00	3229.87	1501.46	9123.33
5	4520.00	3554.83	1494.89	9569.72
		Run No. 15		
1	8712.00	4036.48	1689.44	14437.92
2	8808.00	4994.74	1633.37	15436.11
3	8872.00	5984.34	1634.41	16490.75
4	8688.00	5414.90	1644.02	15746.92
5	8824.00	4690.83	1623.66	15138.49

Table 21. Annual Operating Cost-Constrained Budget Normal Distribution of Lead Times and Demand Size with a Uniform Distribution for Time Between Demands with Reduced Lead Times

Run Number	Cost of Ordering	Cost of Backorders	Cost of Holding Stock	Total
		Rule No. 1		
1	4296.00	6646.61	1584.94	12527.55
2	4296.00	6295.39	1548.36	12139.75
3	4384.00	8171.44	1570.19	14125.63
4	4304.00	7024.31	1574.53	12902.84
5	4256.00	6800.43	1593.83	12650.26
		Rule No. 10		
1	4304.00	5526.29	1673.63	11503.92
2	4344.00	5740.42	1636.47	11720.89
3	4208.00	5275.71	1692.99	11176.70
4	4352.00	4711.74	1624.98	10688.72
5	4296.00	5082.55	1694.77	11073.32
		Rule No. 11		
1	5216.00	6440.39	1499.55	13155.94
2	5296.00	7393.40	1518.57	14207.97
3	5320.00	6160.51	1524.15	13004.66
4	5432.00	8616.45	1473.55	15522.00
5	5168.00	5179.22	1553.06	11900.28
		Rule No. 12		
1	6288.00	8317.23	1562.52	16167.75
2	6280.00	7679.99	1623.23	15583.22
3	6216.00	9416.12	1583.57	17215.69
4	6312.00	9112.20	1589.84	17014.04
5	6416.00	6425.89	1598.18	14440.07
		Rule No. 13		
1	6160.00	5625.79	1560.43	13346.22
2	5888.00	5818.82	1578.59	13285.41
3	6104.00	7594.47	1598.79	15297.26
4	6024.00	7003.52	1539.03	14566.55
5	5936.00	7031.80	1585.84	14553.64

Table 21 (Continued)

Run Number	Cost of Ordering	Cost of Backorders	Cost of Holding Stock	Total
		Rule No. 14		
1	4480.00	9139.27	1512.17	15131.44
2	4448.00	6176.97	1531.23	12156.20
3	4464.00	6940.87	1536.42	12941.29
4	4480.00	6919.68	1508.01	12907.69
5	4392.00	5237.17	1540.45	11169.62
		Rule No. 15		
1	8768.00	10824.08	1672.85	21264.93
2	8664.00	9901.83	1690.72	20256.55
3	8808.00	13113.23	1661.73	23582.96
4	9064.00	11048.57	1687.13	21799.70
5	8712.00	11749.15	1700.10	22161.25

Table 22. Annual Operating Costs-Constrained Budget Inventory System in a Completely Deterministic Mode with Reduced Lead Times

Run Number	Cost of Ordering	Cost of Backorders	Cost of Holding Stock	Total
		Rule No. 1		
1	4240.00	119.29	1641.72	6001.01
2	4224.00	57.33	1668.03	5949.36
3	4208.00	57.66	1670.53	5936.19
4	4240.00	55.35	1668.67	5964.02
5	4224.00	58.72	1670.43	5953.15
		Rule No. 10		
1	4392.00	123.84	1755.37	6271.21
2	4392.00	75.73	1781.87	6249.60
3	4352.00	70.83	1783.18	6206.01
4	4384.00	72.79	1783.67	6240.46
5	4384.00	69.79	1784.57	6238.36
		Rule No. 11		
1	5280.00	154.07	1605.11	7039.18
2	5272.00	92.88	1623.21	6988.09
3	5280.00	109.98	1619.17	7009.15
4	5256.00	94.44	1634.82	6985.26
5	5296.00	93.13	1632.08	7021.21
		Rule No. 12		
1	6256.00	391.00	1697.16	8344.16
2	6296.00	356.85	1720.09	8372.94
3	6256.00	360.51	1715.42	8331.93
4	6264.00	349.37	1726.76	8340.13
5	6304.00	345.43	1727.45	8376.88
		Rule No. 13		
1	6008.00	323.15	1588.14	7919.29
2	6056.00	252.44	1687.30	7995.74
3	6024.00	268.48	1657.49	7949.97
4	6024.00	256.10	1624.92	7905.02
5	6048.00	267.40	1675.39	7990.79

Table 22. (Continued)

Run Number	Cost of Ordering	Cost of Backorders	Cost of Holding Stock	Total
		Rule No. 14		
1	4528.00	218.18	1634.89	6381.07
2	4536.00	154.43	1661.42	6351.85
3	4504.00	172.09	1660.35	6336.44
4	4528.00	137.11	1665.57	6330.68
5	4520.00	175.85	1660.93	6356.78
		Rule No. 15		
1	8976.00	286.75	1790.95	11053.70
2	9056.00	262.97	1818.63	11137.60
3	9024.00	241.95	1817.46	11083.41
4	9032.00	246.88	1817.43	11096.31
5	9056.00	248.20	1817.38	11121.58

APPENDIX D

GLOSSARY OF TERMS (NON-GASP)

1.	BAC	The current number of backorders for any item.
2.	BAL	The difference between the reorder position and the inventory position at the time an order is placed. This quantity is ordered in addition to the reorder quantity to improve the performance of the model that uses formulas developed strictly for unit demands.
3.	COSB	The total annual cost of backorders incurred by the system.
4.	COSH	The cost of holding all items in stock for one year.
5.	COSI	The cost of all items purchased for a one year period of time.
6.	COSO	The cost incurred in purchasing COSI in one year; the cost of ordering for one year.
7.	CUMBAC	The cumulative number of items backordered from the initial period of simulation to the end of simulations.
8.	DEM	The quantity demanded when a demand occurs, variable, and following a normal distribution.
9.	DUEIN	The quantity currently on order for an item.

10.	INPOS	Inventory position, or stock on hand plus on order minus backorders.
11.	IR	The inventory decision rule used during one simulation run.
12.	ISTOCK	The number of lines selected for analysis by simulation. In this research ISTOCK = 17.
13.	ISTOP	The integer number of years that the simulation was to be run.
14.	IYEAR	An indicator of the number of years the simulation has run.
15.	K	A variable used to initialize the uniform random number generator in Subroutine 14.
16.	ONHAN	The current number of items on hand.
17.	ORD	The number of items of a line demanded at one time, with the total number accumulated used as a check on the system.
18.	QSTOCI	The reorder quantity if an item is stocked by a rule. This quantity (i) would be the optimal reorder quantity if there were no constraints placed on the system and (ii) the order quantity if the item is stocked, but not at full unconstrained amount.
19.	REC	The amount of stock received based upon QSTOCI and BAL. See SEM.
20.	REORDI	The reorder position.

21. SEM The total amount of stock ordered; determined by sum of QSTOCI and BAL.

22. TSTOP The number of years the simulation is to run.

23. XOH The amount of stock on hand whenever the Accounting Subroutine is called.

APPENDIX E

SAMPLE OUTPUT OF THE SIMULATION MODEL

Table 23. Initial Conditions of DATAI(I,J)

INITIAL CONDITION OF DATAI(I,J)

COLUMN NO. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1.	16.	0.	0.	16.	0.	0.	0.	38.	2.00	.301	120.00	8.00	2.4	0.
2.	112.	0.	0.	112.	0.	0.	0.	338.	2.49	.187	390.00	8.00	3.7	0.
3.	130.	0.	0.	130.	0.	0.	0.	198.	4.90	.322	210.00	8.00	1.3	0.
4.	8.	0.	0.	8.	0.	0.	0.	19.	5.99	.192	480.00	8.00	6.1	0.
5.	5.	0.	0.	5.	0.	0.	0.	14.	6.90	.211	240.00	8.00	3.0	0.
6.	125.	0.	0.	125.	0.	0.	0.	176.	9.00	.216	330.00	8.00	1.5	0.
7.	54.	0.	0.	54.	0.	0.	0.	74.	9.98	.219	90.00	8.00	3.7	0.
8.	83.	0.	0.	83.	0.	0.	0.	90.	11.00	.283	150.00	8.00	1.9	0.
9.	107.	0.	0.	107.	0.	0.	0.	113.	18.99	.308	300.00	8.00	1.2	0.
10.	25.	0.	0.	25.	0.	0.	0.	22.	19.12	.200	360.00	8.00	1.6	0.
11.	20.	0.	0.	20.	0.	0.	0.	36.	23.59	.194	450.00	8.00	4.9	0.
12.	0.	0.	0.	0.	0.	0.	0.	3.	30.80	.206	540.00	8.00	8.5	0.
13.	26.	0.	0.	26.	0.	0.	0.	33.	36.49	.199	270.00	8.00	2.2	0.
14.	1.	0.	0.	1.	0.	0.	0.	4.	53.16	.221	510.00	8.00	3.0	0.
15.	0.	0.	0.	0.	0.	0.	0.	2.	74.99	.303	420.00	8.00	6.2	0.
16.	0.	0.	0.	0.	0.	0.	0.	2.	85.79	.304	180.00	8.00	9.4	0.
17.	0.	0.	0.	0.	0.	0.	0.	2.	103.49	.201	60.00	8.00	8.3	0.

COLUMN 1 PRODUCT NUMBER
COLUMN 2 ON HAND QUANTITY
COLUMN 3 DUE IN QUANTITY
COLUMN 4 CURRENT NUMBER OF BACKORDERS
COLUMN 5 INVENTORY POSITION
COLUMN 6 CUMULATIVE BACKORDERS
COLUMN 7 NUMBER OF ORDERS PLACED TO DATE
COLUMN 8 QUANTITY ORDERED
COLUMN 9 REORDER QUANTITY
COLUMN 10 UNIT COST
COLUMN 11 INVENTORY HOLDING COST
COLUMN 12 BACKORDER COST
COLUMN 13 ORDERING COST
COLUMN 14 MEAN TIME BETWEEN DEMANDS
COLUMN 15 NUMBER ORDERED IF OSTOCI IS ZERO

Table 24. Annual Costs, Rule 10, Year 1

YEAR 1

THE INVENTORY DECISION RULE USED IN THIS SIMULATION WAS

NUMBER 10-REDUCE THE REORDER QUANTITY BY ONE HALF

PRODUCT NO.	UNIT COST	COST OF PURCHASED ITEMS	COST OF ORDERING	COST OF BACKORDERS	COST OF HOLDING STOCK
1.	2.00	2044.00	200.00	66.23	10.99
2.	2.49	15687.00	136.00	847.07	88.92
3.	4.93	36838.20	288.00	557.58	159.16
4.	5.99	2911.14	176.00	285.01	12.76
5.	6.90	1704.30	136.00	19.10	12.11
6.	9.00	56970.00	272.00	319.72	209.57
7.	9.93	30708.46	272.00	260.82	103.23
8.	11.00	65813.00	480.00	226.16	215.16
9.	18.99	148919.58	480.00	825.75	415.16
10.	19.12	34702.80	600.00	270.89	62.46
11.	23.59	30501.87	248.00	357.67	131.51
12.	30.80	1416.80	120.00	16.77	9.49
13.	36.49	82248.46	496.00	580.35	133.09
14.	53.16	6963.96	256.00	7.72	30.77
15.	74.99	5399.28	272.00	31.60	24.40
16.	85.79	3517.39	160.00	3.21	30.65
17.	103.49	5071.01	192.00	2.80	22.97
		531417.22	4784.00	4678.42	1672.41

Table 25. Condition of DATAI(I,J), Year 1

YEAR 1

COLUMN NO. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1.	11.	43.	0.	54.	114.	25.	1022.	38.	2.00	.301	120.00	8.00	2.4	984.
2.	132.	0.	0.	132.	404.	17.	6300.	338.	2.49	.187	390.00	8.00	3.7	6280.
3.	57.	216.	0.	273.	898.	36.	7518.	198.	4.90	.322	210.00	8.00	1.3	7375.
4.	0.	21.	1.	20.	95.	22.	486.	19.	5.99	.192	480.00	8.00	6.1	474.
5.	6.	0.	0.	6.	16.	17.	247.	14.	6.90	.211	240.00	8.00	3.0	246.
6.	56.	189.	0.	255.	341.	34.	6330.	176.	9.00	.216	330.00	8.00	1.5	6200.
7.	100.	0.	0.	100.	605.	34.	3077.	74.	9.98	.219	90.00	8.00	3.7	3031.
8.	70.	103.	0.	173.	477.	60.	5983.	90.	11.00	.283	150.00	8.00	1.9	5893.
9.	41.	129.	0.	170.	1127.	60.	7842.	113.	18.99	.308	300.00	8.00	1.2	7779.
10.	6.	24.	0.	30.	222.	75.	1815.	22.	19.12	.200	360.00	8.00	1.6	1810.
11.	22.	0.	0.	22.	78.	31.	1293.	36.	23.59	.194	450.00	8.00	4.9	1291.
12.	1.	0.	0.	1.	5.	15.	46.	3.	30.80	.206	540.00	8.00	8.5	45.
13.	38.	0.	0.	38.	530.	62.	2254.	33.	36.49	.199	270.00	8.00	2.2	2242.
14.	2.	0.	0.	2.	4.	32.	131.	4.	53.16	.221	510.00	8.00	3.0	130.
15.	0.	2.	0.	2.	13.	34.	70.	2.	74.99	.303	420.00	8.00	6.2	70.
16.	1.	0.	0.	1.	3.	20.	41.	2.	85.79	.304	180.00	8.00	9.4	40.
17.	1.	0.	0.	1.	9.	24.	49.	2.	103.49	.201	60.00	8.00	8.3	48.

COLUMN 1 PRODUCT NUMBER
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COLUMN 12 BACKORDER COST
COLUMN 13 ORDERING COST
COLUMN 14 MEAN TIME BETWEEN DEMANDS
COLUMN 15 NUMBER OF ITEMS DEMANDED

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